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SPACE STATION NEEDS, ATTRIPUTES, AND ARCHITECTURAL OPTIONS
Final Study Report
Summary Briefing

APRIL 1983

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APPROVED BY

DAVID C. WENSLEY
CHIEF PROGRAM ENGINEER - SPACE STATION

CONTRACT NO. NASW-3687

MCDONNELL DOUGLAS ASTRONAUTICS COMPANY-HUNTINGTON BEACH
5301 Bolsa Avenue, Huntington Beach, California 92647 (714) 896-3311

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The "Space Station Needs, Attributes and Architectural Options" study was conducted by the McDonnell Douglas Astronautics Company at Huntington Beach, California, under contract to NASA Headquarters. Engineering specialists from MDAC-St. Louis and MDTSCO at Houston and KSC supported the MDAC-Huntington Beach study team in the definition and analysis of candidate Space Station missions and required operations. McDonnell Douglas has been a major contractor in all U.S. manned space programs to date and has participated in nearly all major Space Station studies since the early 1960s.

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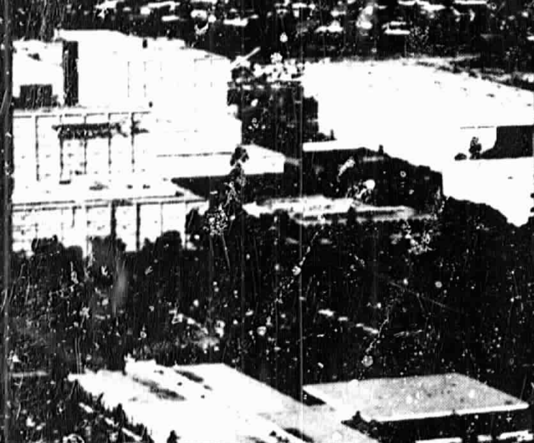

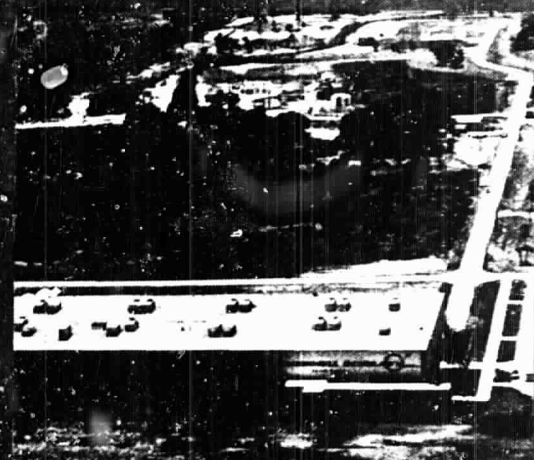

MDAC SUPPORT TEAMS

A comprehensive team of consultants and contractors joined McDonnell Douglas to perform this study in the responsibility areas shown on this chart. A key feature of the MDAC methodology is the use of "Mission Advisory Panels." These are panels of specialists whose backgrounds and skills are aligned with the Space Station Mission Categories. The MDAC team includes an outstanding group of consultants from the commercial, scientific and aerospace industry areas. Since the mid-term report, an additional consultant, Geoscientific Systems, Inc., has been added to the team to advise on Earth and lunar sensing missions and lunar basing concepts. Booz, Allen & Hamilton's contract has been extended to provide additional coverage of candidate mission sponsors in the materials processing and manufacturing area.

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MDAC SUPPORT TEAMS

Consultants

- Booz, Allen & Hamilton
  - Commercial Missions
  - Benefits Analysis
- MDAC — St. Louis
  - Commercial Missions
- Stanford Research Institute
  - National Defense Missions
- Dr. John Logsdon
  - Program Planning

Subcontractors

- Ford Aerospace
  - Communications Missions
  - Ground Data System
- Hamilton Standard
  - Environmental Control and Life Support Systems
- Bendix
  - Navigation and Control
- Vought/LTV
  - Teleoperators

Mission Advisory Panels

- Science and Applications
- Commercial Missions
- National Security Missions
- Operational Missions
- Technology Missions

Changes Since Mid-Term

Added: Geoscientific Systems — Remote Sensing
Increased Scope: Booz, Allen & Hamilton

BRIEFING TOPICS

This summary briefing covers all major topics addressed in the study work statement except National Security Missions which are reported separately to DoD.

The study has produced a detailed mission model which identifies the principal needs of representative missions in all mission categories listed. The major social, economic, technological, commercial, scientific and cultural benefits of each of these missions has been evaluated to provide a basis for ranking or prioritizing the missions within the set. This establishes not a preferred sequence for performing the missions, but a priority basis for building Space Station capability in orbit.

The requirements demanded by this prioritized mission set provide the architectural design criteria for the space system.

In all probability, the Space Station system will be constructed to support a multi-disciplined set of missions such as those included in the prioritized mission model. However, other mission scenarios are possible. To test the sensitivity of system architecture to changing mission emphasis, three other mission scenarios have been examined as listed on this chart.

For each architecture and each scenario, total program costs and schedules have been generated.

BRIEFING TOPICS

- Approach and Summary
- Mission Needs:
  - Science and Applications
  - Operations
  - Technology
  - Commercial
- Mission Benefits and Prioritization
- Requirements for Space Station Facilities
- Architectural Options Versus Mission Scenarios
  - Prioritized Mission Model
  - Science/Applications Emphasis
  - Operations and Technology Emphasis
  - Commercial Emphasis
- Program Costs and Schedules
- Conclusions/Recommendations

FEATURES OF MDAC APPROACH

The scope of this study demands the use of computerized data sorting and analysis techniques. This approach, coupled with MDAC's extensive background data base accumulated in over 20 years of Space Station studies, has enabled the evaluation of hundreds of candidate missions. From these a final model of 88 missions has been selected. The benefits to be accrued from performing these missions in space have been individually analyzed.

The MDAC study has placed special emphasis on commercial mission opportunities. Our success in developing commercial launch vehicles and upper stages, plus our experience in developing the electrophoresis process for the commercial production of pharmaceuticals in space, provided us valuable insight into the opportunities and problems of space commercialization. Our search for new mission opportunities and sponsors has been spearheaded by Booz, Allen & Hamilton, who have identified several exciting new commercial prospects for space.

The individual function and resource requirements of each mission in our 88 mission set have been summed into time-phased composite requirements to drive the selection of Space Station architecture. We have devised an integrated architecture approach based on repeated application of modular elements as a means to provide the most architectural flexibility at least cost. Finally, our capability and architecture build-up concept has been fitted to a realistic budget profile and balanced against a budget-constrained availability of mission equipment.

FEATURES OF MDAC APPROACH

- Computerized Analysis
  - Missions • Architecture • Cost
- Extensive Use of MDAC Data Base
- Mission Advisory Panels to
  - Define Missions • Assess Benefits
- Emphasis on Early Commercial Missions
  - Electrophoresis — MDAC-St. Louis
  - New Missions — Booz, Allen & Hamilton
- Integrated Architecture — Modular Approach
- Budget-Constrained, "Build-To-Budget"
  - Architecture • Mission Model

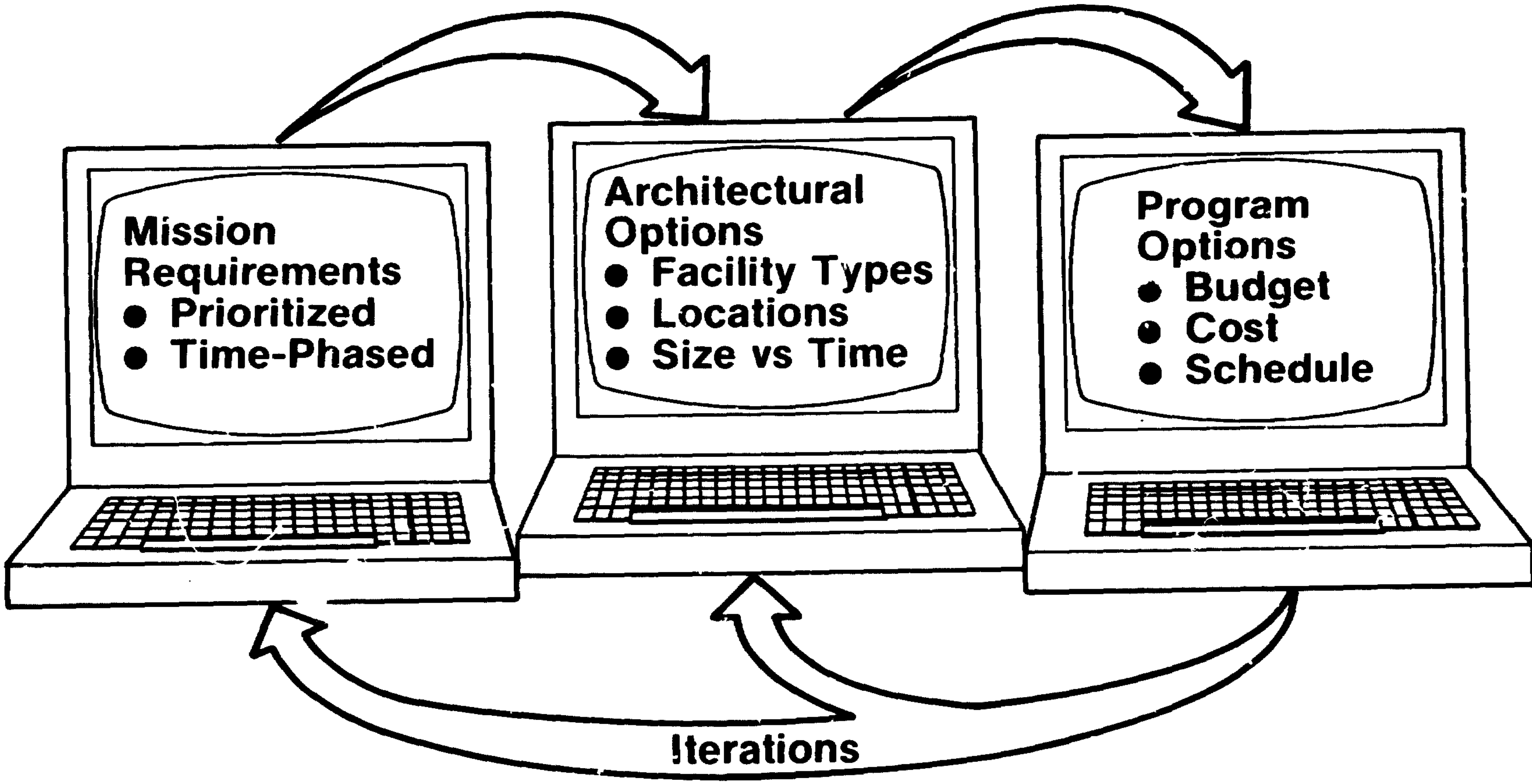
MDAC'S STUDY APPROACH

This illustrates the three major computerized analytical tools used to support this mission analysis study. These analytical tools, developed with company funds, are designed with compatible interfaces so that mission requirements feed directly into the architecture definition program and this output drives the cost and schedule estimating programs. In addition, output tapes from the Mission Requirements Data Base programs are compatible with Langley Research Center's computerized mission model.

Use of these tools has allowed a first complete iteration of the study results at mid-term and several iterations of architectural options in the second half of the study. Some of these results are provided in summary form in this report.

These tools were developed in anticipation of an extended system analysis and concept definition effort and are available to support follow-on studies as required.

MDAC'S STUDY APPROACH



- Computertized Analysis Allows
  - Quick Response
  - Multiple Iterations

MDAC STUDY ACCOMPLISHMENTS

This study has the unique features of an extremely broad scope of investigation, ranging from basic mission definition to total program cost estimating, coupled with a short period of performance. This has demanded a wide range of personnel skills and quick response to task needs. In the opinion of this study team, all original objectives have been met and the results provide a valuable planning base for definition of the Space Station program. A list of the major products and achievements of this study is provided on the adjacent chart.

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MDAC STUDY ACCOMPLISHMENTS

- Developed Prioritized, Time-Phased Mission Model
- Completed Benefits Assessment
  - All Missions
  - 34 Factors: Economic, Social, Cultural, Technological
- Identified New Candidate Commercial Mission and Users
- Performed Economic Assessment of OTV
- Evaluated 12 Major Architectures; 4 Mission Scenarios
- Developed Program Costs and Schedules
  - All Architectures
  - All Scenarios
  - Subsystem Level to Total Program

FINDINGS

The results of this study provide valuable planning data for the Space Station system's detailed definition. This chart summarizes the findings.

The mission needs strongly indicate that a manned space facility, operated on a continuous basis, is essential if we are going to fully develop the emerging commercial opportunities in space. Further, our growing inventory of high value space assets dictates that we give serious consideration to developing a capability to service and maintain these assets in space -- and avoid the cost and rigors of performing these functions from the ground or on the ground. Similar facilities in orbit will be necessary if we are to develop a lower cost, higher performance transportation capability to serve our GEO and HEO orbit transfer needs.

On a priority basis, our initial capability should provide laboratories for continuous, multi-discipline research and development in space. This, coupled with a capability to do limited satellite servicing and to conduct external operations with satellites, platforms and technology development hardware, including the assembly of large structures, will provide us with the ability to do our most important early missions. With reasonable subsystem capability, a single Space Station located in 28.5 degree orbit can accommodate over 70% of our selected missions.

As one of the principal mission categories, Sciences and Applications will benefit greatly from access to a manned Space Station in low inclination orbit but will require other facilities at higher inclinations. Science and Applications is the largest mission group examined. The extent to which the total mission set can be accomplished is largely a question of mission equipment costs and available budget. The use of a prioritization system will aid the selection of high value missions.

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FINDINGS

- Manned Space Facility Essential for
  - Commercial and Technology R&D
  - Satellite Servicing and Maintenance
  - Economic, Reusable GEO Transportation
- Most Urgent Needs
  - R&D Lab
  - Limited Operations Base
- Single Space Station at 28.5 deg
  - Accommodates Over 70% of Missions
- Science and Applications
  - Will Benefit Greatly
  - Need Other Facilities: Platforms, Satellites
  - Limited by Mission Costs

FINDINGS
(CONTINUED)

The Space Station program is a large scale endeavor offering enormous benefits to all aspects of our society. To keep the program affordable, it will be necessary to take advantage of the cost savings opportunities it will make available. Space Station must be understood as a facility offering large scale utilities and services to many users on a time-share basis. This is similar to any multi-purpose facility on the ground. Most necessary resources for payloads (power, data, thermal control, coarse pointing, communications, etc.) will be readily available to the users. This clustering of payloads and sharing of central resources eliminates the subsystem costs normally associated with satellite development and makes special payload equipments, such as those used on short duration Spacelab missions, readily adaptable to long term Space Station use. We have termed the use of the previously flown "experienced" payloads as "legacy missions" in our analysis and strongly recommend the continuing use of such legacy payloads as a cost saving technique.

Use of the Space Station as a focal point for conducting space operations and as a collection and distribution center for mission data will also lead to major new operating efficiences. By staging our space operations from a vantage point in low Earth orbit, we can significantly reduce the number of Shuttle flights needed for servicing and deploying payloads and for initiating higher energy orbit transfers. We will also remove the severe mission duration and payload power constraints that now limit our space operations performed in Shuttle. As a Data Center, the Space Station will allow us to accumulate mission data from remote satellites and platforms, as well as from payloads positioned on the Space Station, and re-transmit these data at high rate through the TDRS link. This procedure alone could lead to a $40 million annual savings in communications services.

The Space Station architecture, which will include both manned and unmanned facilities placed in different orbits, demands the efficiency of a modular design approach with as much multiple application use of subsystem elements as possible. The planning and analysis necessary to achieve these efficiencies and cost savings, and to resolve critical issues such as autonomy and the role of man versus machine, are more complex and will have more long range impact than the specific subsystem design and technology issues to be encountered.

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FINDINGS
(Continued)

- Major Cost Savings Come From:
  - Adaptation of Legacy Missions
  - Clustering Payloads/Resource Sharing
  - Use of Space Station as Operations and Data Center
- Unified Design, Modular Approach
  - Saves Cost
  - Enables Growth
- Most Complex Technology Issues Are:
  - System Level
  - Operational

SCIENCE AND APPLICATIONS MISSIONS

A mission model of 57 Science and Applications has been defined. These missions include:

- 19 missions in Solar and Astrophysics
- 3 missions in Communications Research
- 8 missions in Earth Environment
- 16 missions in Earth and Planetary Exploration
- 6 missions in Life Sciences
- 5 missions in Materials Processing

These missions will address basic questions of science which can profit from on-orbit measurements and observations. The full 25 decades of wavelength emitted by the sun and cosmos will be observed, as compared to the six decades observable from the earth. This will enable the better understanding of the universe, the solar system, and the interaction between the sun and the earth's weather and climate.

These missions will address the better utilization of the earth's resources and environment to the general benefit of society. Communications costs have dropped by an order of magnitude and volume has grown even more rapidly because of the use of satellite relay systems. Continued growth of communications will require better utilization of facilities and extension of capability. New products for health care, new understanding of biological sciences, and new materials for electronics resulting from space research and processing will benefit all of society. Observation of the earth's environment and resources will aid in control of the environment, management of resources, conservation of fragile ecosystems, and development of renewable resources.

The Space Station offers unprecedented economic, social and cultural benefits to the U.S. and the world through the peaceful uses of space.

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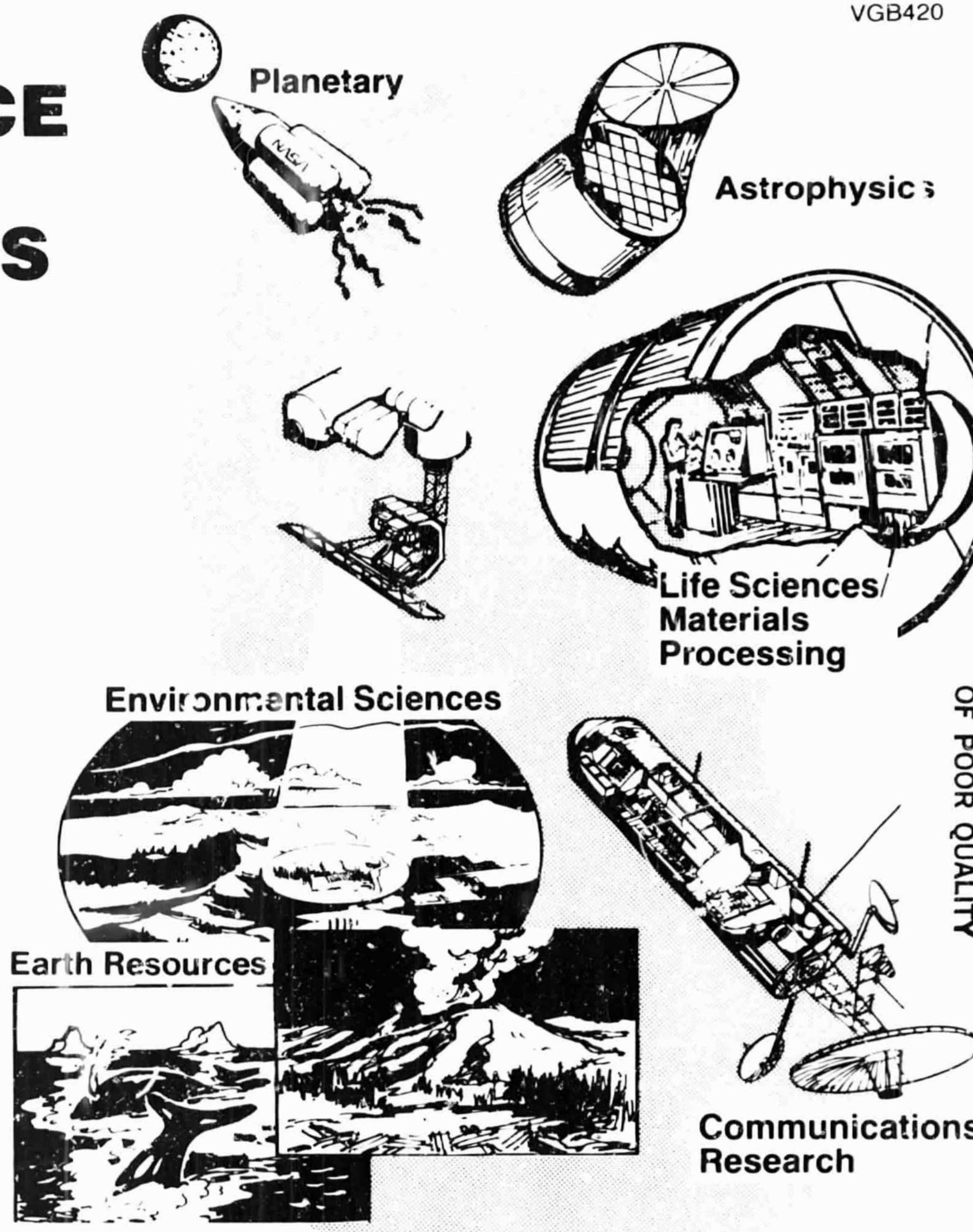
SPACE SCIENCE AND APPLICATIONS MISSIONS

Benefits:
- Economic
- Social
- Cultural

- Origin and Fate of the Universe
- Solar System Evolution
- Earth/Sun Interaction
- Health and Welfare
- Resource Management



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SPACE STATION CONTRIBUTION
SCIENCE & APPLICATIONS MISSIONS

A manned Space Station will be of enormous value in helping us achieve our Science and Applications objectives. For some mission groups, such as Life Sciences and Materials Processing, a manned Space Station is a practical necessity. The rate of progress by using intermittent short duration flight opportunities is severely limited.

For the majority of science and applications missions, Space Station will provide high value operational support. This support will contribute to mission achievement and reduce the overall cost of mission hardware and operations. It will also enable the maintenance, repair and servicing of free-flying payloads and provide opportunities for manned interaction to enhance data acquisition of interpretation.

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SPACE STATION CONTRIBUTION SCIENCE AND APPLICATIONS MISSIONS

SPACE STATION ENABLES

- Life Sciences Research
- Materials Processing
- Real-Time Manned Observations

SPACE STATION ROLE

- R&D Lab
- Process Development Facility
- Observatory Base

SPACE STATION SUPPLEMENTS

- Astrophysics
- Earth and Planetary
- Environmental Sciences
- Communications

SPACE STATION OPERATIONS

- Testing/Development
- Assembly/Deployment
- Service/Repair
- Launching Base
- Data/Communications Central

EVALUATION OF MAN IN-ORBIT INFLUENCES

The unique capabilities of man can be of major benefit to many missions. As a Scientist/Observer, man has proved his worth on Skylab and Shuttle missions. Capabilities of special value are pattern recognition, judgmental decision making, and flexibility in responding to changing needs. As a Development Engineer, tactile and manipulative skills add to those above. As a Service Technician, man's judgment, tactile, and manipulative skills are especially valuable in servicing a wide variety of equipment. Man also brings to orbit some performance limitations that must be dealt with. Chief among these are acceleration disturbances and effluent release.

Seventeen parameters relating to the beneficial and detrimental effects of man in orbit were evaluated for each mission. These parameters were then examined to determine mission accommodation requirements in categories of required, desired, or acceptable for accommodation on a Space Station, a platform, or a dedicated satellite.

There are six missions in our model that are committed to dedicated satellites. The mission equipment is designed for on-orbit maintenance and can be serviced from Space Station. There are 13 missions which require accommodation on a Space Station, because of the key roles played by man. An additional 18 missions will substantially benefit from manned presence. There are eight missions which prefer the disturbance and effluent free environment of a platform, but will benefit from close support by man in orbit. Twelve missions can be accommodated on either a Space Station or platform.

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EVALUATION OF MAN IN-ORBIT INFLUENCES

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● = Required ○ = Acceptable
◐ = Desirable • = Intolerable

			ASTROPHYSICS												COMM		
			ASO (SOT)	SIRTF	STAR LAB	SCRN	TRIC	XRO	HRS	XTE	HTM	VLBI	HEIE	CRO	RFI	OSP	CRF
Beneficial	SCIENTIST OBSERVER	REAL-TIME DATA ANALYSIS	●	◐	◐	○	○	◐	◐	○	○	○	○	○	○	◐	◐
		MULTIPLE SENSOR USE	◐	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
		SENSOR MODE/PARAMETER SELECTION	◐	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
		COOPERATION WITH PRINCIPAL INVESTIGATOR	◐	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
		TARGET SELECTION	◐	◐	◐	○	○	◐	◐	◐	◐	○	◐	○	○	○	●
	DEVEL ENGR	SENSOR OPERATION	●	●	●	○	○	○	○	◐	○	○	◐	○	◐	◐	●
		SENSOR EVALUATION	◐	◐	◐	○	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	○	○	○	○	◐
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	TECH-NICIAN	[illegible]	[illegible]	[illegible]	◐	●	●	◐	◐	[illegible]	●	○	●	●	◐	○	●
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		ONBOARD SAFETY	○	○	○	○	○	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	○	○	○
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		REPETITIVE DUTY CYCLES	○	○	○	○	○	○	○	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	○	○	○
		Space Station Candidate	◐	○	○	◐	◐	○	◐	○	○	◐	◐	◐	◐	◐	●
		Platform Candidate	○	◐	◐	○	○	○	○	○	○	◐	○	○	◐	○	

57 Science and Applications Missions

Optional 12

SPACE STATION

Require	13
Desire	18
Need Service	6

PLATFORM

Desire	7
Accept	1

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ORBIT REQUIREMENTS

SCIENCE AND APPLICATIONS MISSIONS

Orbital inclination affects the value of Science and Applications missions in several ways. Earth and environment observation missions prefer high inclination to increase coverage of the earth's surface. Sun synchronous orbits are preferred to achieve constant sun angle. Solar observation missions can profit by the continuous view of the sun afforded by a sun synchronous orbit. Astronomy missions tend to prefer the low charged particle radiation environment of low inclination to limit noise and the possibility of saturation of sensitive detectors. Infrared, microwave, and radio astronomy missions all profit from higher inclination. Constancy of solar heating helps maintain alignment of large optical systems. High inclination provides longer north-south baselines for very long baseline interferometry, and rapid precession provides the desired range of baseline inclination in a short time.

The mission set was analyzed to determine both the preferred orbital inclination for each mission and the relative value of mission accomplishment at other inclinations. Many of the missions were found to have a high tolerance for alternate inclinations. In addition, many of the missions are insensitive to orbital inclination. These missions will tend to cluster at low inclination to take advantage of higher traffic and lower energy to achieve orbit.

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ORBIT REQUIREMENTS SCIENCE AND APPLICATIONS MISSIONS

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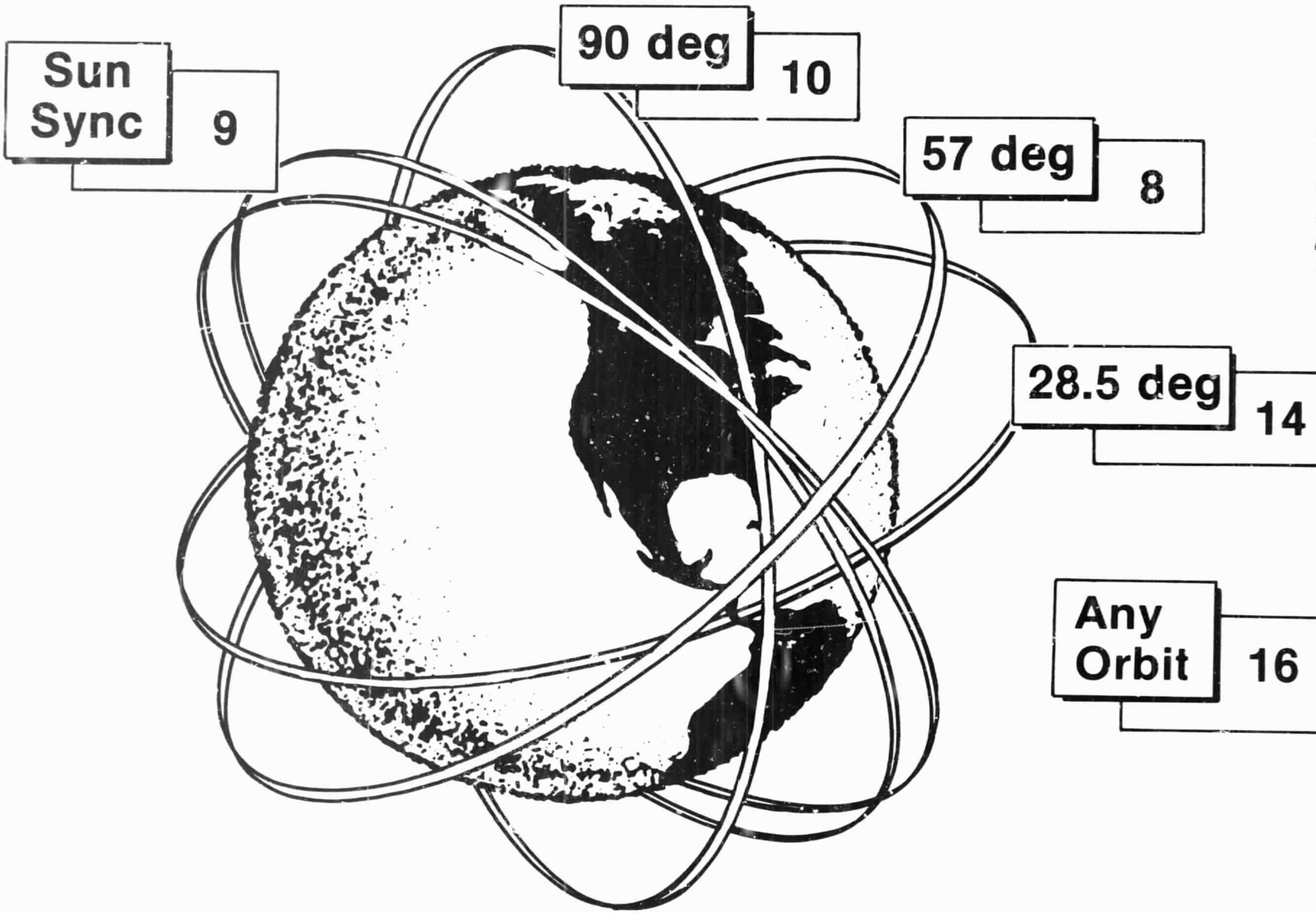

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MISSION DEMAND

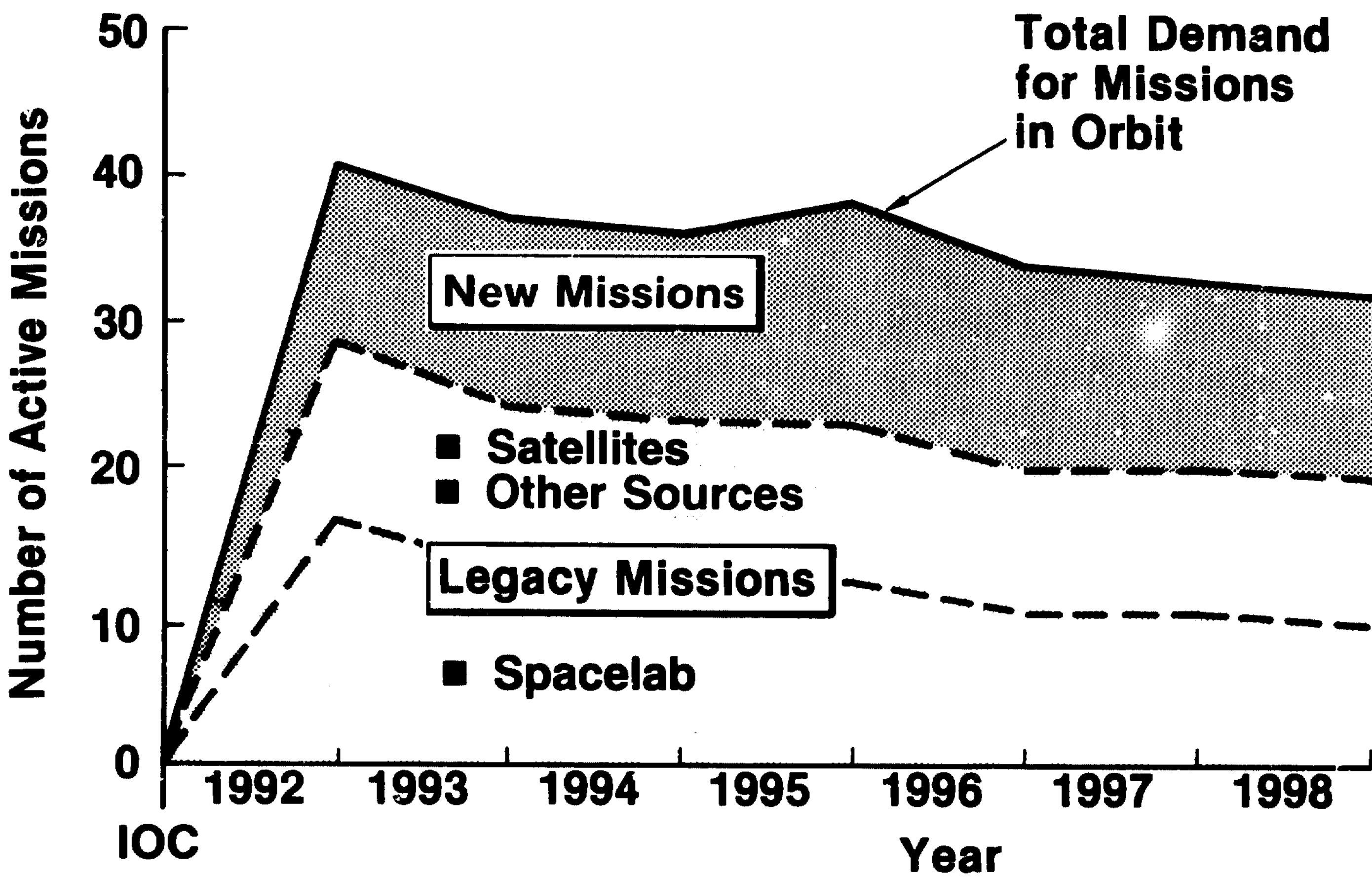
SCIENCE AND APPLICATIONS

The desired Science and Applications mission time phasing was examined. These availability dates considered the orderly progression of missions, without considering budget constraints. A majority of the missions were found able to be candidates for an initial Space Station operating capability (IOC) in 1992.

The missions defined in the study have three lineage sources. Twenty of the missions were derived from the Spacelab program. Of these, 10 are from fully operational missions, and 10 from Spacelab-developed equipment. There are 11 missions derived from equipment that has been flown on other satellites. There are 20 new missions and six designated dedicated satellites to complete the 57 mission model.

Neglecting budget constraints, 43 missions could be ready to incorporate into a Space Station in 1992. The remaining 14 missions from our 57 mission Science and Applications Mission Model would phase in over the next decade. To produce equipment for 43 missions in a 1992 Space Station, beginning in 1986, would require three Spacelab transfer starts per year, two starts of previously flown equipment, and two completely new starts per year. This level of activity is inconsistent with a realistic budget projection and steps were taken to reduce the number of missions in the set.

MISSION DEMAND
SCIENCE AND APPLICATIONS



MISSION COST ESTIMATES - SCIENCE AND APPLICATIONS

To gain some insight into a budget constrained program, a $400 million per year budget for mission equipment was assumed to begin in 1988. The budget was increased to $600 million per year in 1993 to allow for operating costs. Mission starts were programmed considering priority category, time phasing, and estimated cost. The mission equipment cost estimates were derived using the Aerospace Spacecraft Cost Estimating Model. Adjustments were made for the degree of prior development. Annual on-orbit operations costs were estimated at 10% of the equipment fabrication costs. For legacy missions with reduced fabrication costs, operation costs were estimated as though the mission were a new start. A ground operations cost of $9 million per year per mission was assumed for all missions.

Over the 6 year equipment development period from 1987 through 1992, there are eight new equipment starts, 16 Spacelab legacy starts, and nine other legacy starts. During the operating period after 1992, there are about 25 operational missions at a cost of $360 million per year. The $210 million remaining in the budget allows for about 1.2 new equipment starts per year. An additional approximately $30 million is available for upgrading existing equipment or other legacy mission starts.

MISSION COST ESTIMATES SCIENCE AND APPLICATIONS

EQUIPMENT STARTS (1987–1992)

- **New**
  1.3/yr $200 Million/yr
- **Spacelab Legacy**
  2.7/yr $150 Million/yr
- **Other Legacy**
  1.5/yr $50 Million/yr

Assumed Budget
$400 Million/yr

1987 1992

EQUIPMENT STARTS (1993–2000)

- **New**
  1.2/yr $210 Million/yr
- **Other Legacy**
  0.4/yr $30 Million/yr

OPERATIONS

- 25 Missions/Yr $360 Million/yr (Average)

Assumed Budget
$600 Million/yr

1993 2000

BUDGET CONSTRAINED SCIENCE AND APPLICATIONS PROGRAM

The budget constrained program provides for 16 Science and Applications missions in 1992, and growth to 25 in 1993. The number of missions active after 1993 averages about 25. Thirty-four of the 36 missions in the top three priority groups are implemented by 1996. Both of the remaining two missions are started by 1996 and would be ready for flight in the late 1990s. The 34 missions include 11 from Astrophysics, one from Communications, seven from Earth Environment, 10 from Earth and Planetary Exploration, four from Life Sciences and three from Material Processing. The missions on orbit in 1993 include 14 Spacelab and Spacelab derivative missions, seven other satellite legacy missions, and five new program start missions.

This budget constrained Space Station equipment development program provides a very representative set of high value missions with adequate time phasing and provides the funding for comprehensive operational support.

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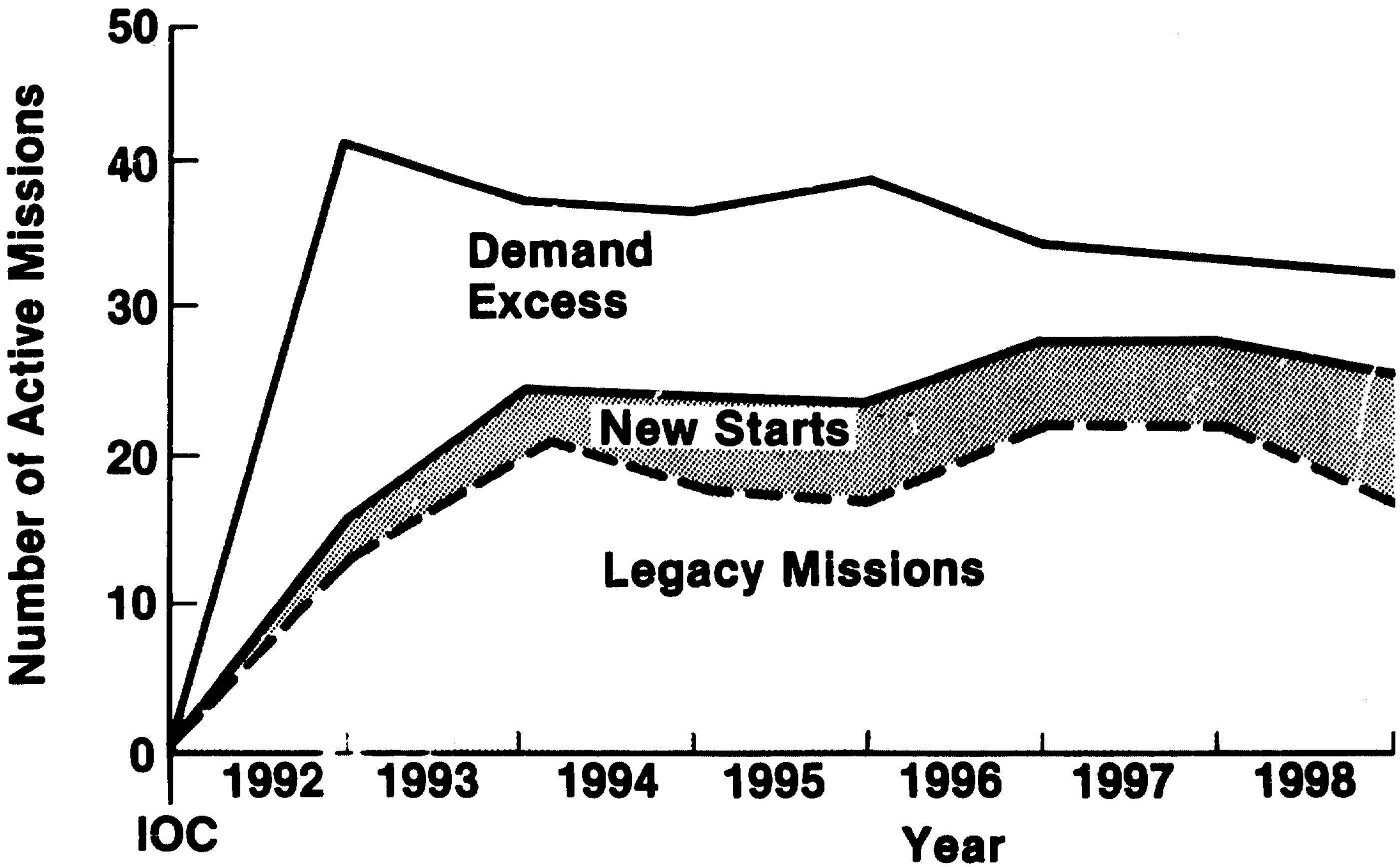
BUDGET-CONSTRAINED SCIENCE AND APPLICATIONS PROGRAM



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SPACE OPERATIONS AND TECHNOLOGY MISSIONS

Space Operations is a broad category of missions encompassing orbital activities which benefit other missions. The earliest opportunities will be in Satellite Servicing. Maintenance and repair from a Space Station base can keep extremely valuable facilities such as Space Telescope operating at peak performance with fewer Space Shuttle launches required.

A reusable orbit transfer vehicle would operate primarily between near earth and geostationary orbits. Fuel can be carried up on the Space Shuttle, or even scavenged from the external tanks of the Shuttle. The benefits are measured in reduced Shuttle launches.

On-orbit assembly or construction of large structures will open the door to several extremely valuable missions. Candidates include the Large Deployable Reflector (high resolution infrared and microwave astronomy) and a communications platform for geostationary orbit. Space Operations plays an enabling role for these missions which permits achieving scientific and commercial objectives which would otherwise be unattainable.

Robotics operations provide an alternative to manned EVA operations. Potential benefits are increased efficiency for man on orbit, reduced hazards to man and extension of Space Operations to orbits, such as geostationary, which would not be planned for manned access in the near term.

Space Technology missions are directed at two objectives. One objective is to develop the enabling technology for the Space Operations missions. The second is to develop technology for improving, upgrading and extending the life and value of the Space Station itself. These latter objectives will also benefit future manned or unmanned excursions into the Solar System.

SPACE OPERATIONS AND TECHNOLOGY MISSIONS

Benefits:
Economic
Technological

- Reduced STS Flights
- Lower Transportation Costs
- Spacecraft Reuse
- Larger Systems
- Multiuse Systems
- Commercial Attraction
- Enabling Technology

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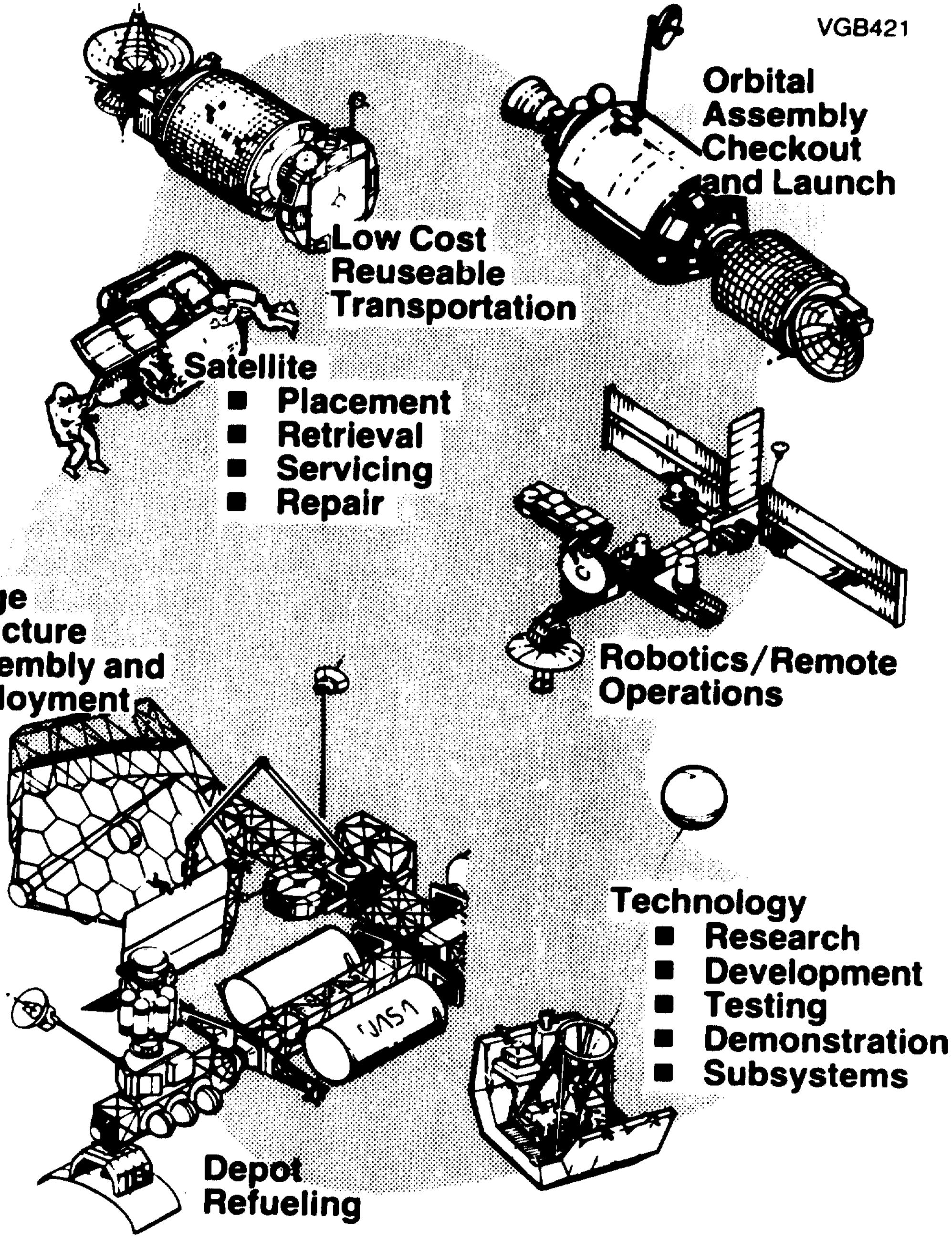

MISSION SERVICES

A manned Space Station provides a unique and logical base for providing a variety of mission services. These services include satellite servicing where the manned station can provide visual observation and hands-on troubleshooting; assembly and construction of large payloads where the station can provide an extended on-orbit manned presence; and payload deployment where the station provides checkout and launch of mission vehicles to other destinations freeing the Space Shuttle for other missions.

These services place requirements on the Space Station for facilities and equipment. A Teleoperator Maneuvering System (TMS) will be able to perform most of the orbital maneuvering of payloads, such as satellite or instrument package placement and retrieval. TMS is limited to orbital inclination and altitudes in close proximity to the Space Station.

A remote Manipulator System (RMS) is needed to grapple and position payloads outside the Space Station. Astronauts working in Extravehicular Activity (EVA) will require airlocks to leave and enter the Space Station, space suits for life support, means for carrying tools and equipment, and support fixtures at the work stations. An EVA away from the Space Station will require a Manned Maneuvering Unit (MMU). TMS, OTV, payloads and MMU equipment will require external ports for docking to the Space Station and resupply of consumables. Supplies and spare parts for other service missions will need to be stored in or on the Space Station.

On-orbit assembly missions will require the use of the RMS, as well as assembly fixtures for positioning and aligning the structure. Similar fixtures will be necessary in the servicing and repair of large satellites. Successful use of robotics will require video links and displays to allow operator monitoring and interaction with the functions.

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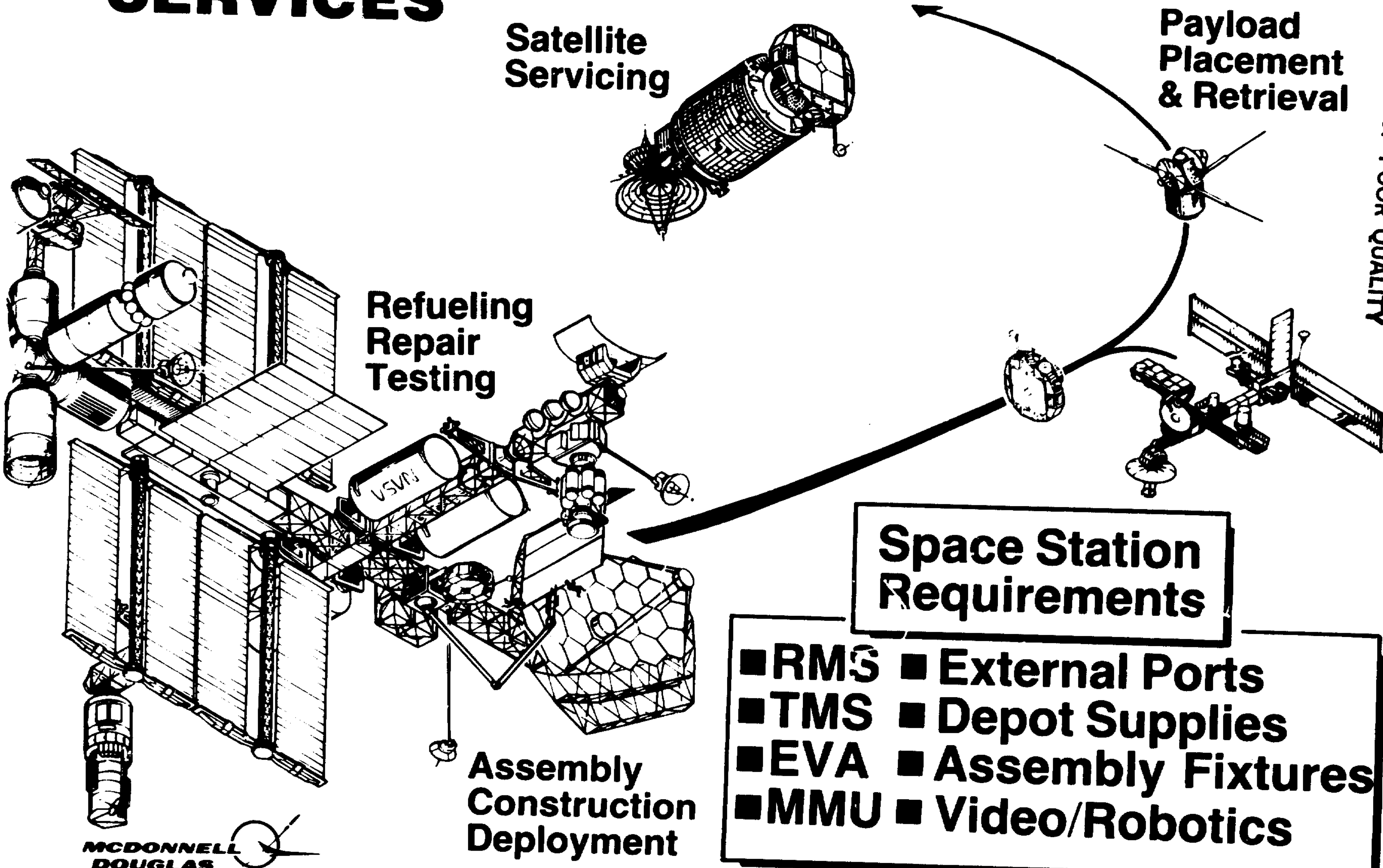
MISSION SERVICES



Space Station Requirements

- RMS
- TMS
- EVA
- MMU
- External Ports
- Depot Supplies
- Assembly Fixtures
- Video/Robotics

SATELLITE SERVICING MISSIONS

On-orbit servicing from the Space Station is the first logical operations mission. In the years 1992-2000 (Space Station operations), there are 13 satellites that are identified as candidates for servicing. These satellites are of high value and are accessible to a Space Station in the indicated orbit. Most are designed for on-orbit servicing.

Seven of the satellites are in a 28.5 degree orbit. Six of these satellites have been designated as orbital service missions in the mission model for the Space Station. The average interval between scheduled maintenance activities is about 2.5 years. When all satellites are on orbit simultaneously, there are over two service missions per year. Each would require a dedicated launch if serviced from the Space Shuttle. Repair of failed equipment will add to the number of service missions and required Shuttle launches.

Dedicated launches are not required for service performed from the Space Station. Replacement parts, supplies and equipment can be taken to the Space Station in advance of the service mission when space is available on the Shuttle. Hence, most Shuttle launches for service would be saved. In addition, repairs can be performed in a timely manner without perturbing the Shuttle launch schedule. The net savings in Shuttle launches is estimated at two to three per year.

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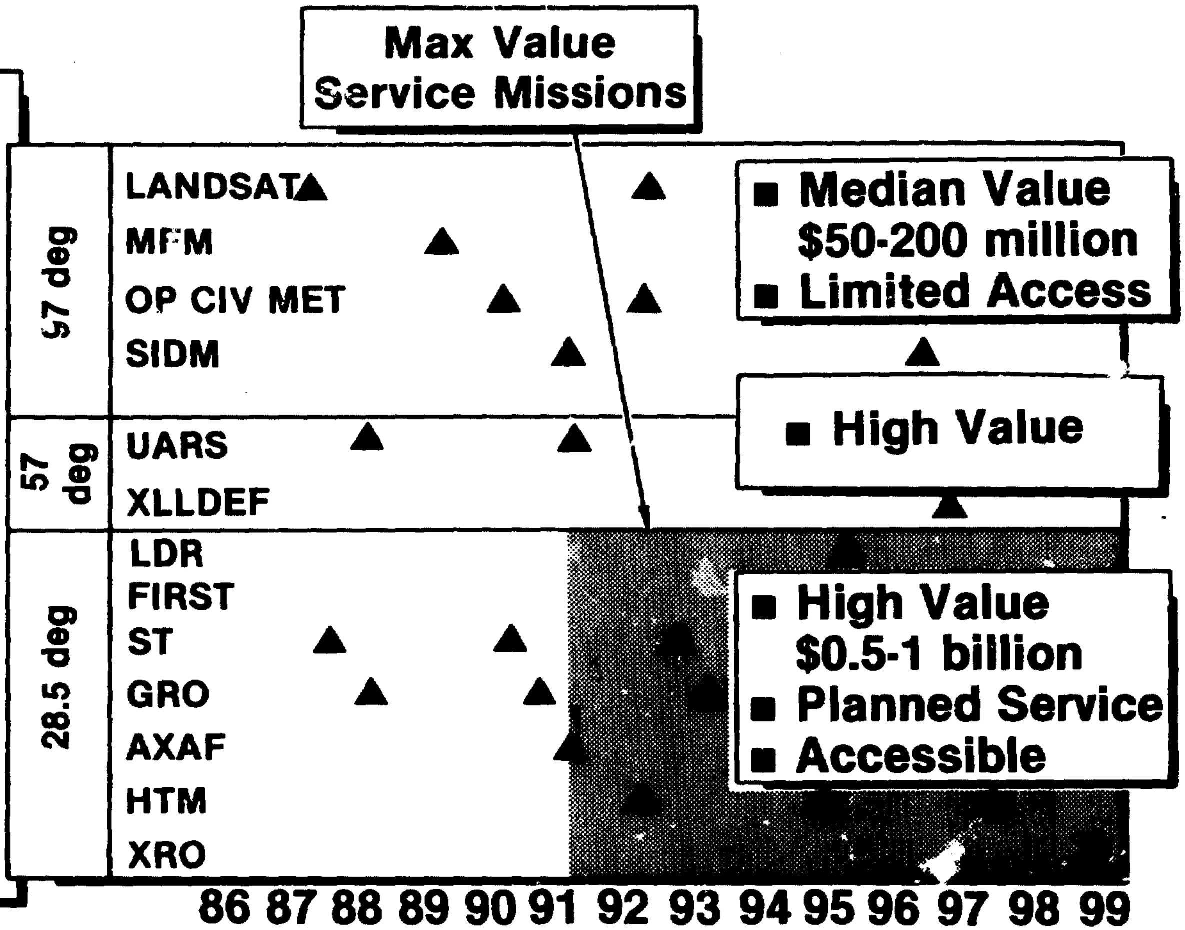
SATELLITE SERVICING MISSIONS

Satellite Servicing Evolution

- Orbiter EVA
- TMS/Orbiter EVA
- TMS/Space Station EVA
- TMS/Space Station Hangar
- TMS Sortie Robotics
- OTV/TMS Sortie Robotics
- Manned OTV



REUSABLE ORBIT TRANSFER VEHICLE

OPERATED FROM SPACE STATION

A reusable OTV is an important contributor to providing cost-effective transportation of payloads into high energy orbits, including geosynchronous placement/retrieval and planetary injection. The Space Station is a necessary operating base for the ROTV, offering the opportunities for assembling mission vehicles, conducting launch operations and performing routine service and maintenance of the ROTV as well as being a propellant depot. To support these functions, the station must be equipped with an RMS, assembly, berthing and docking provisions, propellant storage and transfer capability, and checkout and launch equipment.

The Space Station concept includes an orbital depot capability that allows the ROTV to maximize the use of External Tank residual propellants by scavenging. It also provides a facility for transfer and storage of cryogenics that would be carried in special tanks in the orbiter cargo bay. These tanks would take advantage of any excess payload capability on Shuttle flights that are essentially volume limited. This feature is described as "payload topping."

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REUSABLE ORBIT TRANSFER VEHICLE OPERATED FROM SPACE STATION

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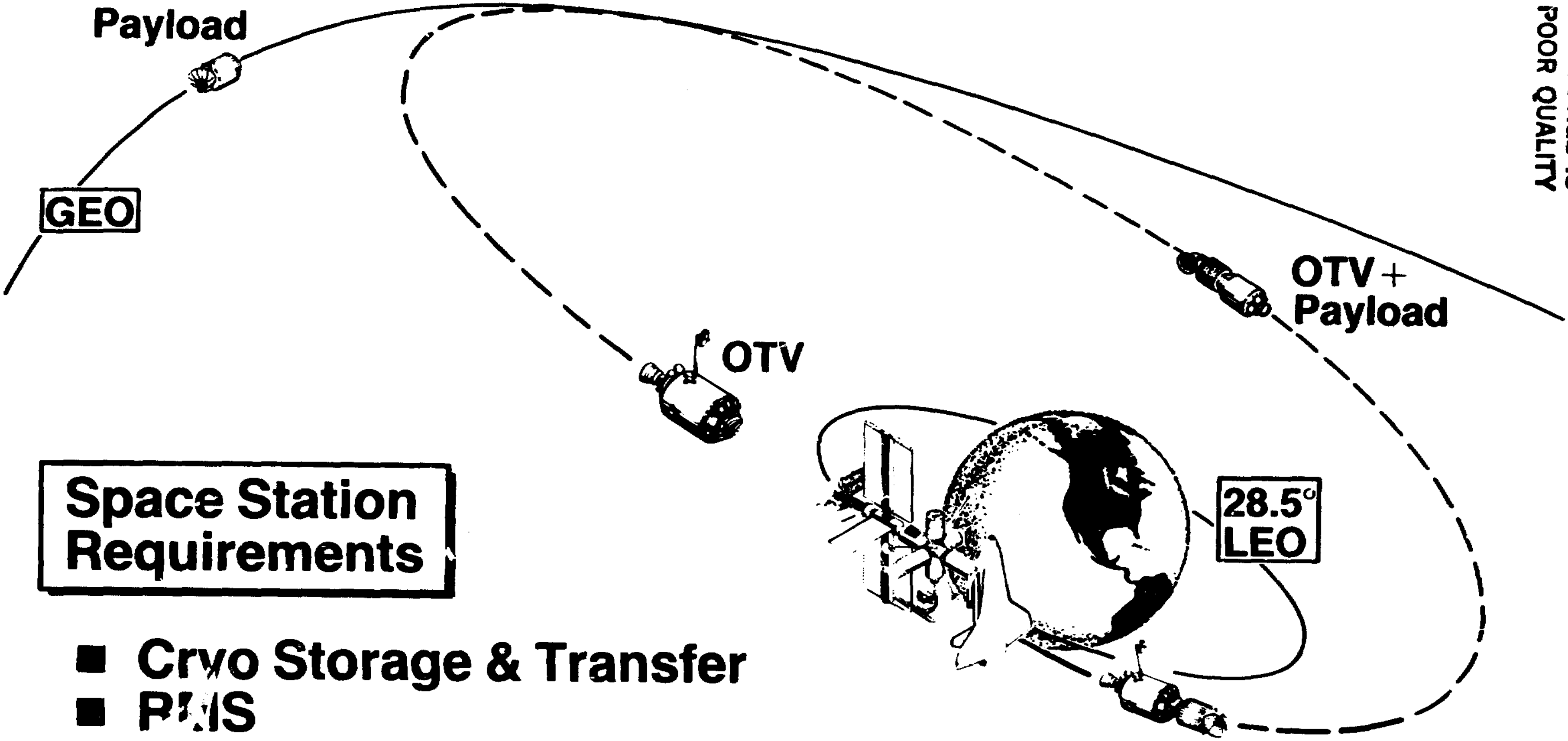

Space Station Requirements

- Cryo Storage & Transfer
- RMS
- EVA/MMU
- Automated Functions
- Assembly Fixture
- Checkout/Launch Equipment

DEDICATED SATELLITE MISSIONS

A traffic model for dedicated satellite missions was developed to compare the economics of alternative orbital transfer vehicle concepts. The references for this model were the NASA Space System Technology Model, 7/81, and the Battelle's Outside User's Payload Model, BCL-NLVP-TM-82-1, July 1982. Two models were projected, a "low" and a "high" number of payloads delivered, with the latter about 40% greater than the former. The reported analysis was based on the low model data.

The model includes those payloads delivered to GEO whose planned method of delivery is the Space Shuttle and upper stages; it excludes those that are projected to be launched on non-Shuttle vehicles such as Delta and Ariane. The model projects 100 payloads to be launched through the year 1997. It was extrapolated at a rate of 13 payloads per year through the year 2000, resulting in 139 payloads to be delivered to GEO. There are 27 different payload types with the majority of payloads being commercial in nature, and having a payload mass less than 3600 Kg. In fact, the average payload mass is 1200 Kg per payload.

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DEDICATED SATELLITE MISSIONS

Reusable OTV Candidates

		#LAUNCHES PER YEAR 90	91	92	93	94	95	96	97	98	99	10 YR TOTAL 00	INC DEG	ALT KM	MASS KG
XAS012	SIMULT ASTRO EXP	1	0	0	0	0	0	0	0	0	0	1	0	GEO	2000
XAS013	FAR UV SPECT EXP	1	0	0	0	0	0	0	0	0	0	1	0	GEO	1000
XCM001	INTELSAT VI	2	1	2	2	0	0	0	0	0	0	7	0	GEO	2004
XCM002	INTELSAT VII	0	0	0	0	1	2	3	2	0	0	8	0	GEO	3636
XCM004	TEL	0	0	0	0	1	0	0	0	0	0	1	0	GEO	702
XCM005	WESTAR	0	0	2	1	0	0	0	0	0	0	3	0	GEO	626
XCM006	TDRS/ADV WESTAR	0	1	0	1	1	1	1	0	0	0	5	0	GEO	2273
XCM007	SATCOM	0	0	1	1	1	1	0	0	0	0	4	0	GEO	895
XCM008	SBS	0	1	0	0	1	1	1	0	0	0	4	0	GEO	550
XCM009	GALAXY														32
XCM010	SYNCOM														14
XCM011	GSTAR														02
XCM013	STC														02
XCM014	DBS														36
XCM016	DATA TRANS														36
XCM017	BANKING														36
XCM018	MAIL														36
XCM019	SATCOL														15
XCM021	TELESAT	1	0	2	0	1	0	0	1	0	0	5	0	GEO	702
XCM022	CHICOMSAT	1	0	0	0	1	1	0	1	0	0	4	0	GEO	702
XCM023	PALAPA	0	1	0	1	0	0	1	0	0	0	3	0	GEO	632
XCM024	MISC	0	1	1	0	1	1	0	0	0	0	4	0	GEO	702
XCM025	NATO	0	0	0	0	0	1	1	0	0	0	2	0	GEO	432
XCM026	TRACK/DATA ACQUISIT	0	0	1	0	0	0	0	0	0	0	1	0	GEO	3000
XEE004	GEO OP/ENV SAT	0	0	1	0	0	0	0	1	0	0	2	0	GEO	874
XEP001	GEOS	2	0	0	0	2	0	0	2	0	0	6	0	GEO	400
XXX002	INSAT	0	1	0	0	1	0	0	0	0	0	2	0	GEO	591

- **139 Payload Deliveries to GEO**
- **27 Payload Types**
- **165,000 kg Delivered**
- **13/Year Average at 1200 kg Each**

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GEO MISSION MODEL TRANSPORT COSTS

The transport costs of the GEO mission model payloads (including orbiter, stages, propellant, and operational charges) were calculated and are compared for expendable and reusable OTV concepts. The expendable OTV would incur over $6 billion in transportation costs for the delivery of the 139 payloads in 10 years. The cost band is bounded by the upper line in which the payloads are delivered singly on the particular expendable OTV best matched to the performance needs (i.e., PAM, IUS, or a cryogenic stage). The lower cost is for multiple payload delivery (up to 4 per mission) on an expendable cryogen stage, and results in a saving of $0.7 billion.

An additional savings of at least $2.3 billion can be realized by using a two-stage reusable OTV (ROTV). This lower cost is because the cost of the stage is averaged over the life of the stage, i.e., 20 missions. The analysis and cost comparison also included single stage ROTV, aerobraked ROTV, and single/multiple delivery of the payloads. The aerobraked ROTV cost is nearly equivalent to the two-stage ROTV, while the single stage ROTV is nearer the cost of the expendable stage.

The 4300 Kg of propellant potentially available by scavenging from the Shuttle flights going to 28.5° (10 assumed available per year) would allow an additional cost reduction of $1.6 billion. In addition to scavenging, a payload topping (use of excess orbiter payload weight capability due to volume limits) of only 3% (97% load factor) would supply all the propellant needed for the two-stage ROTV. As shown, a total cost savings of $4.2 billion over 10 years could be realized by the implementation of the two-stage ROTV over the expendable OTV mode. This is more than adequate to offset the development of the ROTV and the costs of an orbiting propellant depot. Because of the potential high value of this two-stage ROTV with multiple payload capability, it is recommended that indepth systems studies be accomplished to further develop this potential. In addition, it would appear to be a prime candidate for a future commercial enterprise.

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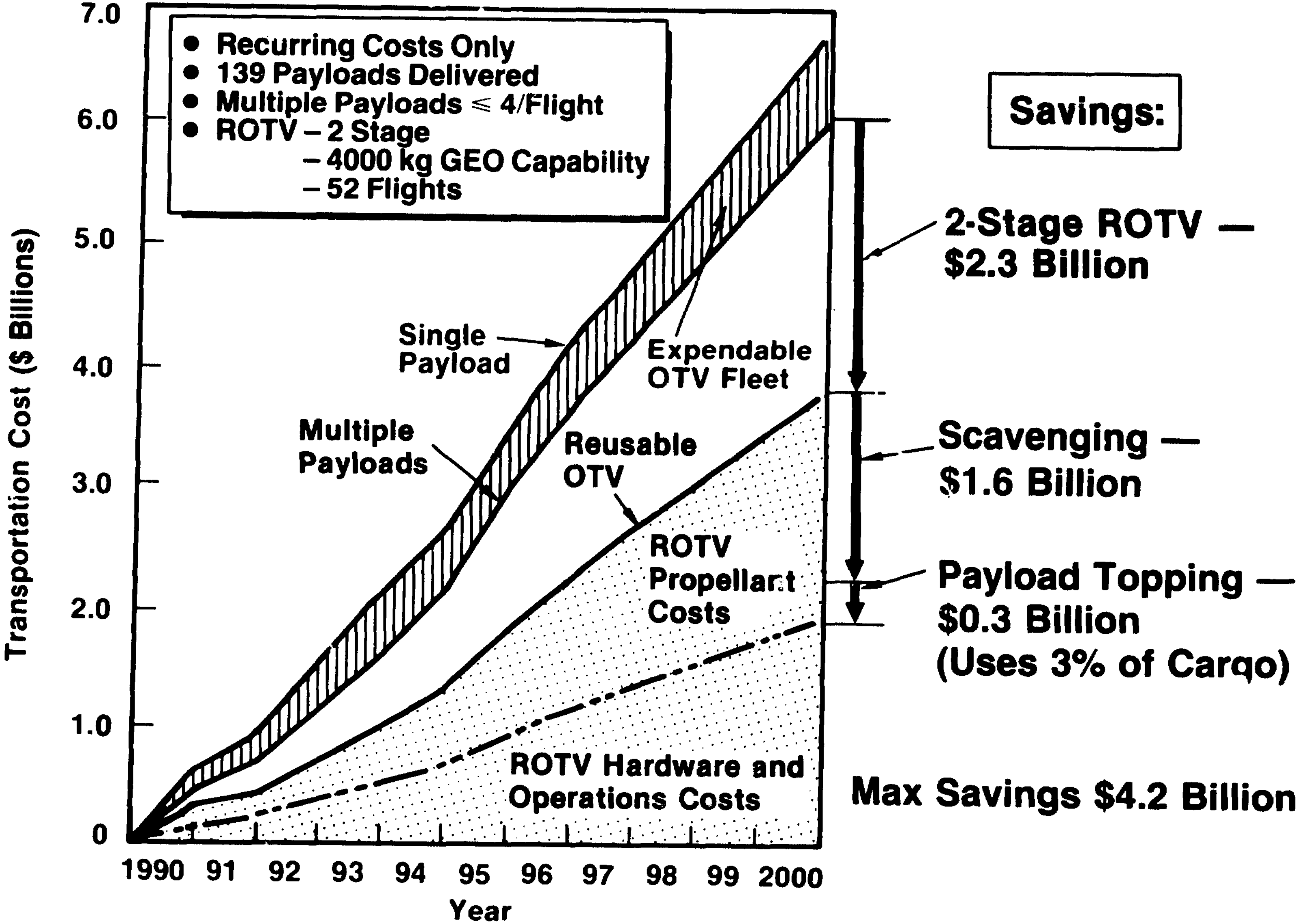
GEO MISSION MODEL TRANSPORT COSTS



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TECHNOLOGY DEVELOPMENT IN ORBIT - MISSION TECHNOLOGY

The technology development missions have two components--those necessary to develop a growth Space Station defined as Subsystem Technology Missions and those necessary to develop advance missions/payloads to be supported by the Space Station, defined herein as Mission Technology Missions.

The final list of Technology Development Missions was selected for our Mission Model from about 75 possibilities identified by NASA and MDAC. This list was refined down to a total of 14 Technology Development Missions covering both categories. To this was added an EVA mission that can be done on Shuttle to round out the necessary technology development. The criteria for refining the mission list included: combining redundant missions and selecting those most responsive to critical needs or "mission drivers."

The chart identifies the Mission Technology Missions required for Advance Mission/Payloads development. The primary drivers for these Mission Technology Missions are: ROTV, Satellite Servicing and Large Structures and Antennas. Five of these missions (listed below) plus the unlisted EVA Mission, relate to ROTV and Satellite Servicing:

- Evaluation of Man's Role
- Fluid Storage and Management
- Satellite Service Technology
- Crew Manipulator/Robotics
- OTV Service Technology

The first three plus the EVA Mission provide the components and functional capabilities development necessary for OTV and satellite servicing, including man/machine relationships. The latter two combine the requisite components into subsystems. These two missions will then develop the integrated subsystems, including the allocation of tasks to EVA, manipulators or robotics. The Space Station portion of the missions will be to complete the development, and verify and demonstrate the respective servicing capabilities.

The other branch of the mission technology effort is the development of the capability to assemble and/or deploy large structures and antennas. These are covered by the Large Structure Construction and Large Structure Control missions and the Zero g Antenna Range Missions. The first two are also a necessary ingredient in a growth Space Station so they are also included in the Subsystem Technology Mission list.

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TECHNOLOGY DEVELOPMENT IN ORBIT

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MISSION TECHNOLOGY

CANDIDATE TECHNOLOGY DEVELOPMENT MISSIONS
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CREW SYSTEMS
 EMESIS STATION
 DISHWASHER/CLOTHES WASHER APPLIANCES
LONG TERM CRYOGENIC FLUID STORAGE TECHNOLOGY
FLUID MANAGEMENT TECHNOLOGY
FIRE SAFETY TECHNOLOGY
CONTROLLED ACCELERATIO
LARGE SPACE POWER SYST
ION THRUSTER EFFECTS O
LIQUID DROPLET RADIATO
...
 DYNAMICS OF LIGHTLY L
SPACECRAFT STRAIN AND
SPACECRAFT MATERIALS T
SPACECRAFT CONTROL TEC
 ADVANCED ADAPTIVE CON
 ADVANCED CONTROL DEVI
 THERMAL SHAPE CONTROL TECHNOLOGY
LARGE ANTENNA DEVELOPMENT/
LSA SHORT AND LONG BASELINE TECHNOLOGY
 DEVEOLPMENT AND UTILIZATION
EARTH OBSERVATIONS INSTRUME
 MEASUREMENT OF AIR P
 CO2 LIDAR FOR
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Space Station Mission Drivers

ROTV

Satellite Servicing

Large Structure Assembly and Deployment

Large Antennas

SELECTED TECHNOLOGY MISSIONS

- Satellite Service Technology
- OTV Service Technology
- Crew Manipulator/Robotics
- Zero-g Antenna Range
- Fluid Storage & Mgmt
- Evaluation of Man's Role
- Large Structure-Construction
- Large Structure-Control

SPACE STATION REQUIREMENTS

- Crew
- EVA/MMU
- RMS
- Voice/Video
- External Ports
- Instrumentation

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TECHNOLOGY DEVELOPMENT IN ORBIT

SUBSYSTEM TECHNOLOGY

The growth Space Station requires Subsystems Technology Development Missions. The "Program Drivers" for these missions are cost, logistics, long life, reliability adn performance. Nine Subsystem Technology Development Missions have been selected for inclusion into the Space Station mission model on the basis of their importance to the key Program issues. The H_2O Recovery, O_2 Recovery, Advanced Radiator and Tether Dynamics Subsystem Technology Development Missions relate to the cost and logistics drivers. The others related to life, reliability and performance. The Subsystems Technology Development Missions of Large Structure Construction and Evaluation of Man's Role are also included in the Mission Technology Development Missions because they support advanced missions as well as growth versions of the Space Station.

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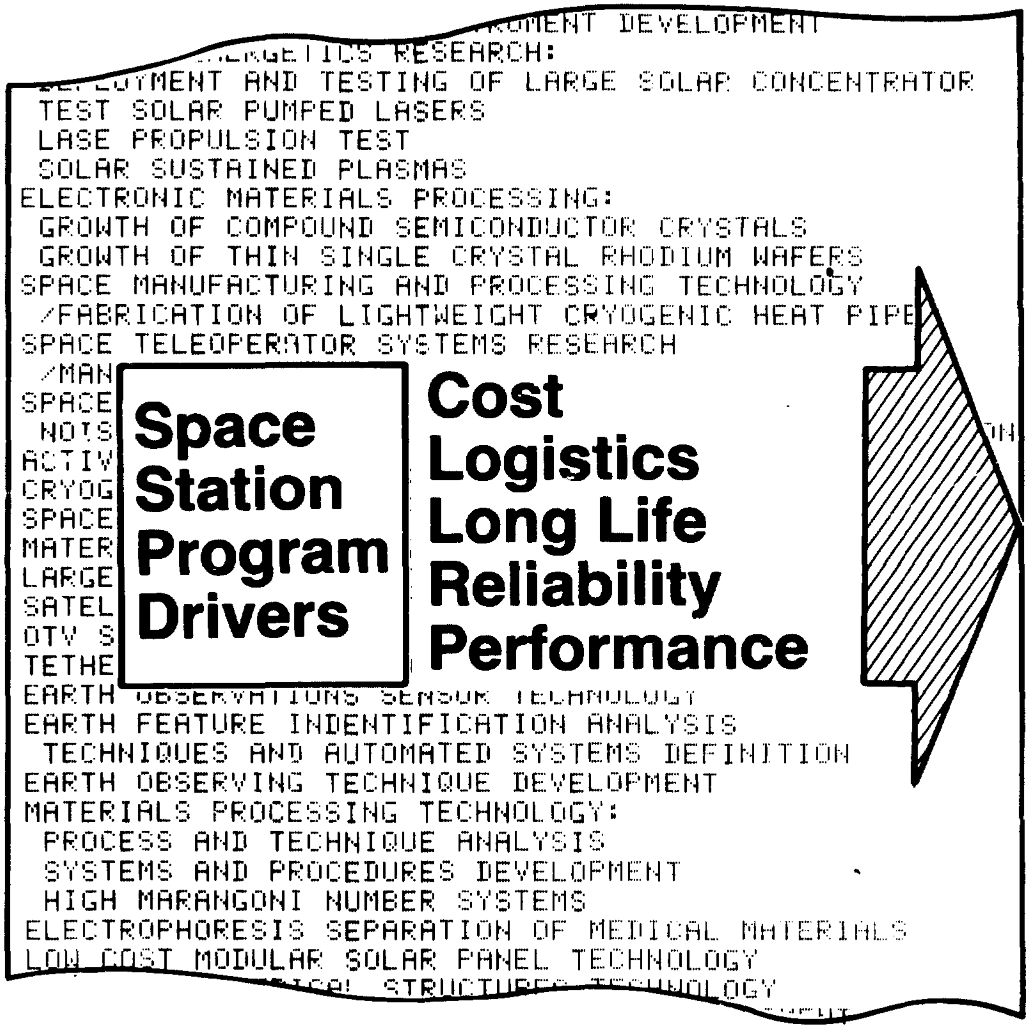
TECHNOLOGY DEVELOPMENT IN ORBIT

SUBSYSTEM TECHNOLOGY



SELECTED TECHNOLOGY MISSIONS

- ECLS H_2O Recovery
- ECLS O_2 Recovery
- Advanced Technology Radiator
- Materials and Coating Technology
- Laser Comm and Tracking
- Tether Dynamics
- Evaluation of Man's Role
- Large Structure-Construction
- Large Structure-Control

SPACE STATION REQUIREMENTS

- Crew • EVA/MMU
- Modular Subsystems
- Shop and Test Equip.
- Voice/Video • Inst.

COMMERCIAL MISSIONS

As defined in the 1982 Office of Technology Assessment publication "Civilian Space Policy and Applications," a commercial activity is one undertaken for profit in the public marketplace and the term "commercialization" implies the transfer of technology from a research and development and/or federally supported phase of activity to a for-profit phase, usually under private sector ownership and control.

The opportunities for the commercialization of space not only include the areas of communications, remote sensing and materials processing, but also for providing commercial launch and transportation services and satellite servicing and other support services to the growing numbers of general users. In the field of Space Transportation, McDonnell Douglas is leading this transition with its company financed Delta 3914 launch vehicle and its Payload Assist Module (PAM) series of upper stages. The potential ten year market from all candidate commercial ventures is projected to be in the 40 to 50 billion dollar range.

Corporate investment in the development of a new product or service is generally undertaken only after a critical appraisal of the relevant technology, the anticipated development cost and anticiapted return, and the market demand. The role of the government has traditionally been to serve as a stimulus to economic development by supporting research in high risk pursuits with potential payback times longer than considered acceptable by private venture capitalists, or for technological developments having obvious social benefits to the populace as a whole.

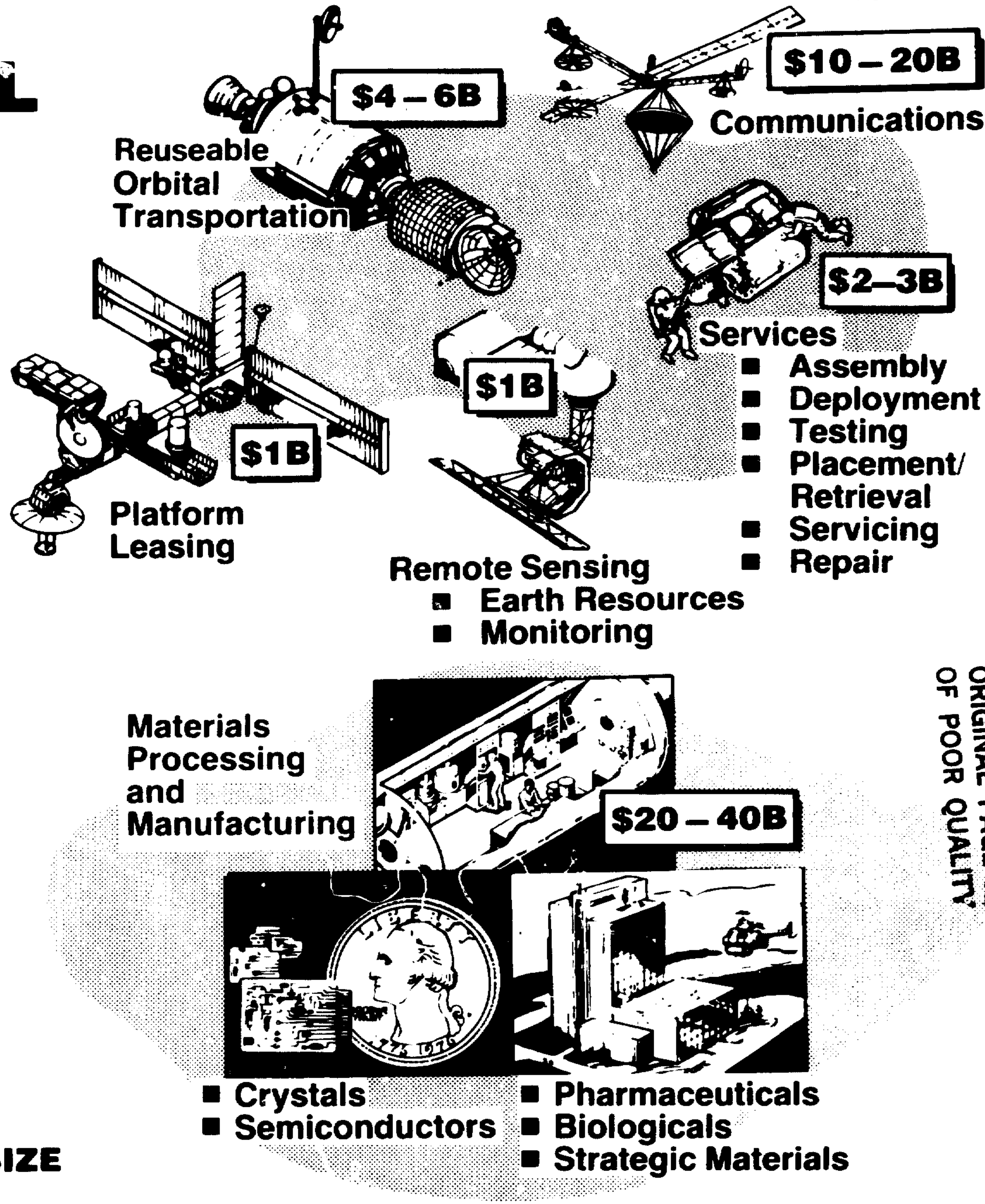
By taking the lead in reducing the risks of space operation, NASA can serve as the enabling agent for achieving the economic, social and technological growth necessary to secure the future for the peoples of the United States and the rest of the free world. If we are successful in fully commercializing space activities, we will open the door to new, high technology industries representing a broad range of medical, technological, economic and consumer product benefits. In addition to demonstrating U.S. world leadership in high technology and free enterprise, we will begin to shift the burden of investment in space from government to private industry--just as we already have in the case of satellite communications.

VGB422

COMMERCIAL MISSIONS

Benefits:
- Economic
- Social
- Technological

- Applies NASA R&D
- Stimulates Economy
- Improves Quality of Life
- Increases US World Leadership
- Provides Return on Investment
- Applies High Technology
- Shifts Investment to Private Industry



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$B 10 YEAR MARKET SIZE

COMMERCIAL COMMUNICATION PLATFORMS

Over the last two decades, the numbers of long distance telecommunications have been increasing at a rate that reflects a doubling period of seven years. If this rate of growth continues into the 1990s, the service demand will far exceed the capabilities of existing systems. The investment required for the space segment alone of the new systems needed will represent investment in the tens of billions of dollars.

Aside from purely economic considerations, there are technological and political barriers to be overcome in closing the demand gap. Issues of the number of orbital slots that can be allocated, and frequency use assignments are issues of a political nature and are resolved through inter-government agencies such as the International Telecommunications Union. The basic problem which must be addressed is to increase, by whatever means necessary, the telecommunications system capacity.

The trend for Satellites to be of increasing size (power, physical size, and capability) has lead to increasing complexity in terms of deployments and more rigid pointing requirements. Good examples are the TDRSS and the INTELSAT 7. With the development of a manned space station and a low thrust orbital transfer vehicle (OTV), problems involved with increasing complexity of satellites may be reduced. The space station could act as a spacecraft test bed, allowing final verification of the communications subsystem. Final alignment of antennas and sensors could be completed without the influence of the 1 "g" environment seen on the earth. A low thrust OTV would allow certain deployments to occur under manned observation. In the event of a deployment failure the problem could be corrected before a final orbit is reached.

With the availability of a space station, then, an opportunity exists to increase the performance and decrease the risk in several areas of commercial communications satellites. The micro-gravity environment may enable commercial satellite builders to test certain subsystems more easily than is currently being done on earth. The non-restricted area may also permit testing that is currently impossible on the ground.

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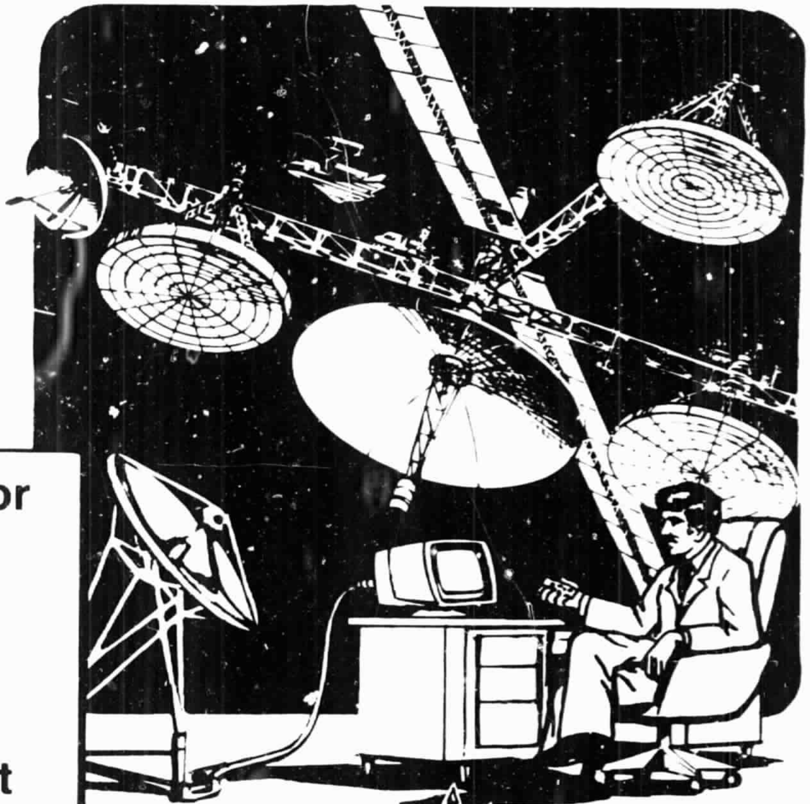
COMMERCIAL COMMUNICATION PLATFORMS

- Long-Distance Telecommunications Market Doubling Every 7 Years
- Geosynchronous Slots Limited
- Large Multi-Antenna Systems Will Be Required



Manned Space Systems Essential for

- Low Cost Transportation
- Structural Assembly/Deployment
- Testing and Checkout
  - — Antenna Alignment
  - — Antenna Pattern Measurement
  - — Propellant Management
  - — Plume Effect Assessment
  - — Materials Aging et al.

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REMOTE SENSING FROM ORBIT

The technological success of programs such as Landsat has been phenomenal. From a commercial standpoint, however, the true market has yet to be established.

On March 8, 1983 President Reagan announced his decision to transfer the government's weather satellites and land remote sensing satellites to the private sector. The next step is to obtain legislative approval of the plan.

Several private companies have expressed interest in pursuing the operation of the current satellite systems as a commercial venture in spite of the fact that actual demand for Landsat data for example is relatively small. It has been estimated that less than 0.1% of the current data base has been utilized.

Organizations that are exploring the commercial market for remote sensing data are predicating their projections on the availability of improved sensors as well as the simultaneous use of multiple sensors to provide data customized to the needs of individual users in a timely and economical fashion.

Computerized image enhancement offers oblique viewing of Landsat scenes combined with topography. As illustrated in the facing page, any pixel coded entity can be combined with radar or conventional altimetry to yield three-dimensional perspective views.

Eventually, artificial intelligence methods can be expected to supplant man in the detection of change or in the recognition of anomalies from space. However, man will be needed to assess rates of change and the significance of the anomalies. He will be needed to perform additional measurements of short term phenomena: spectroscopy of transients, additional sensors to define a hazard, side look of volcanic plumes, etc. Man, if an experienced observer, will have intuition concerning observables. Man will be needed for special study investigations by organizations with proprietary targets.

In summary, artificial intelligence will play an important role in most remote sensing, but manned space systems will be required for all remote sensing in terms of:

a. Teaching (reprogramming) the machines.
b. Short term phenomena requiring immediate actions.
c. Optical viewing of specific targets under special conditions for commercial or proprietary purposes.
d. Maintaining and repairing sensors.

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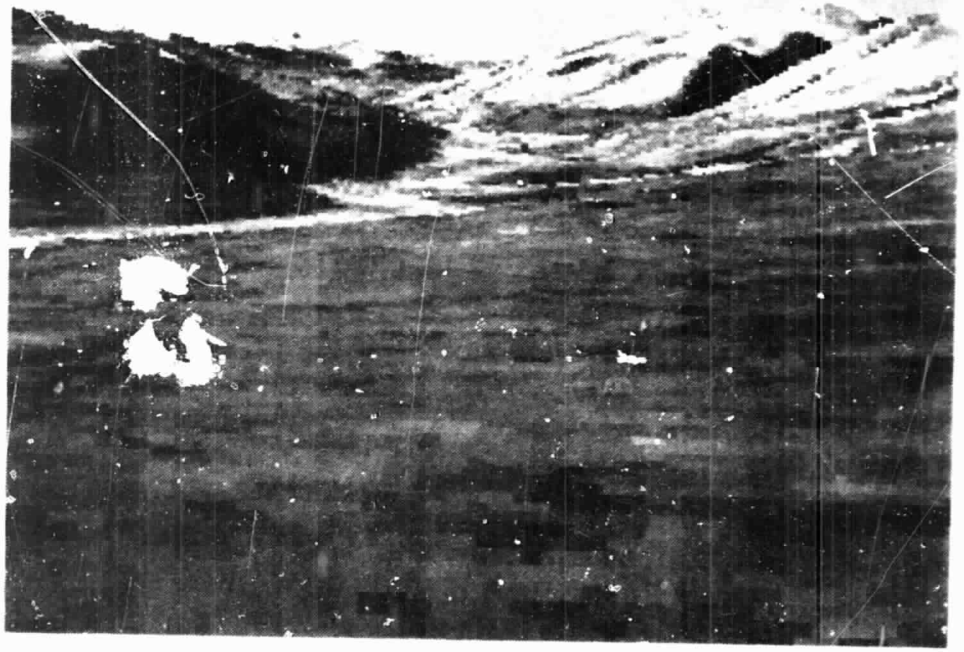
REMOTE SENSING FROM ORBIT

- Commercial Market Still Developing
- Use of Manned Space Systems Allows
  - On-Orbit Maintenance and Servicing
  - Calibration and Alignment of Sensors
  - Multisensor Data Correlation
  - Real-Time Ground Truth Assessment



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MATERIALS PROCESSING AND MANUFACTURING

As a major commercial opportunity, Materials Processing and Manufacturing offers exciting new possibilities for high technology discoveries and a large market potential for the related processes, products and services. A partial list of the product possibilities is shown on this chart.

In the early 1970s, McDonnell Douglas conducted an extensive survey of commercial opportunities in space and selected pharmaceutical production using the continuous flow electrophoresis process as a candidate for development. An electrophoretic separator was constructed and successfully demonstrated in the laboratory. An industry-to-industry agreement was reached with Ortho Division of Johnson and Johnson in which Ortho is responsible for selection, clinical testing and certification of the pharmaceuticals and McDonnell Douglas Astronautics Company - St. Louis, is responsible for the electrophoresis processing. The apparatus was successfully tested on STS Flight No. 4. It is hoped that continued success in this new space industry will inspire the development of other new, high technology processes and products by other commercial sponsors.

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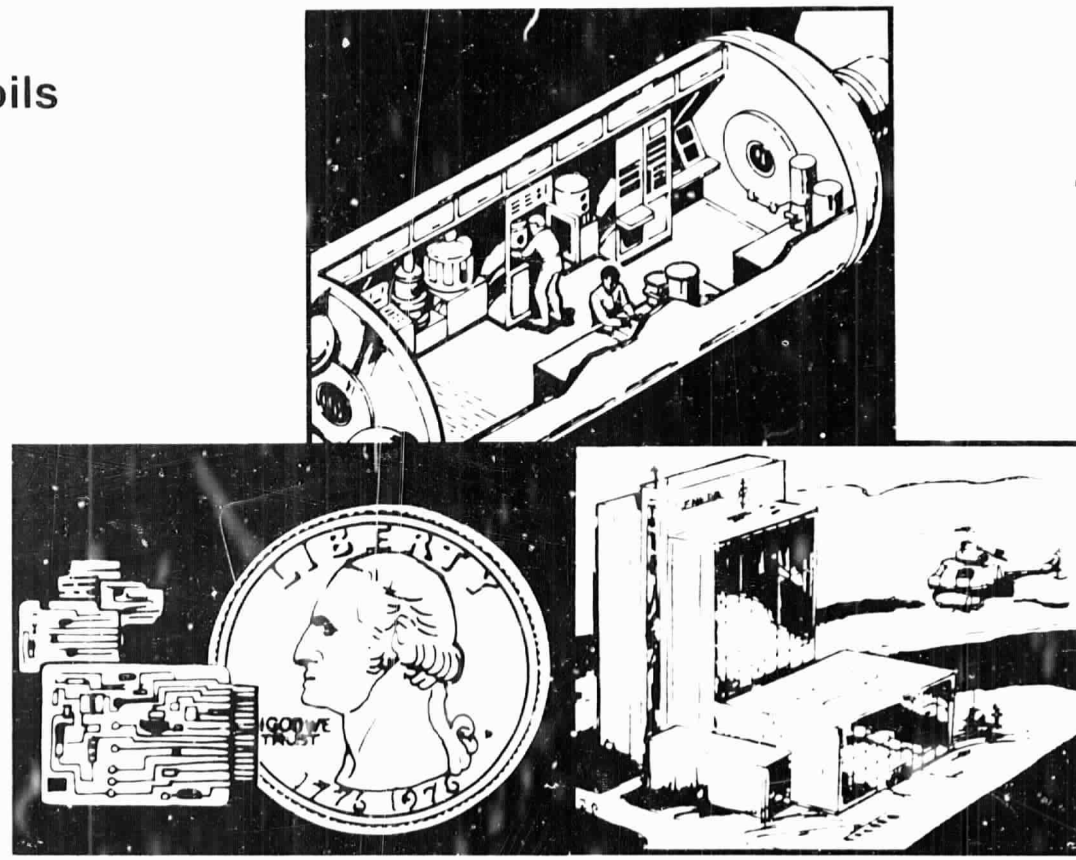
VGP669

MATERIALS PROCESSING & MANUFACTURING

Major Commercial Opportunity

- Pharmaceuticals
- Semiconductors
- Shaped Crystals
- Plastics, Films and Foils
- Alloys and Mixtures
- Ultra-Pure Metals
- Composites
- Biologicals
- Glasses
- Membranes/Films
- Metal Foams
- Lab Services
- Fibers
- Microspheres
- Ceramic/Metal
- Matrix Materials



ELECTROPHORESIS OPERATIONS IN SPACE

In the case of many of the concepts which have been advanced to date in the field of space manufacturing, neither the market economics nor the technological approaches have as yet been fully validated. In fact, of the many potential space manufacturing processes examined over the last two decades, only one has matured to the point of flight demonstration. This is the Electrophoresis Operations in Space (EOS) Program which represents a Joint Endeavor Agreement between NASA and the McDonnell Douglas Astronautics Company and its teammate, the Ortho Division of Johnson and Johnson.

Under the Joint Endeavor Agreement with NASA, MDAC is currently developing the technology to accomplish Electrophoresis Operations in Space (EOS). The development plan involves process proof of principle, pharmaceutical product evaluation and demonstration of a production prototype system. Johnson and Johnson has teamed with MDAC, with the responsibility to conduct the clinical trials, FDA certification and market the product.

The first orbital flight of a prototype EOS facility occurred on STS 4. The equipment was located in the mid-deck of the Orbiter and was accessible to the space crew for scheduled and unscheduled tasks. Scheduled crew activities included cycling the power on and off, starting and stopping the system operation, initializing (zero check), processing the sample product and collecting the product. In addition, photographs of the columnar flow were required for later ground analysis and were taken 14 times per day. The operator was also required to change the sample input and to change the collection trays. A total of six mid-deck flights are scheduled for this initial development plan.

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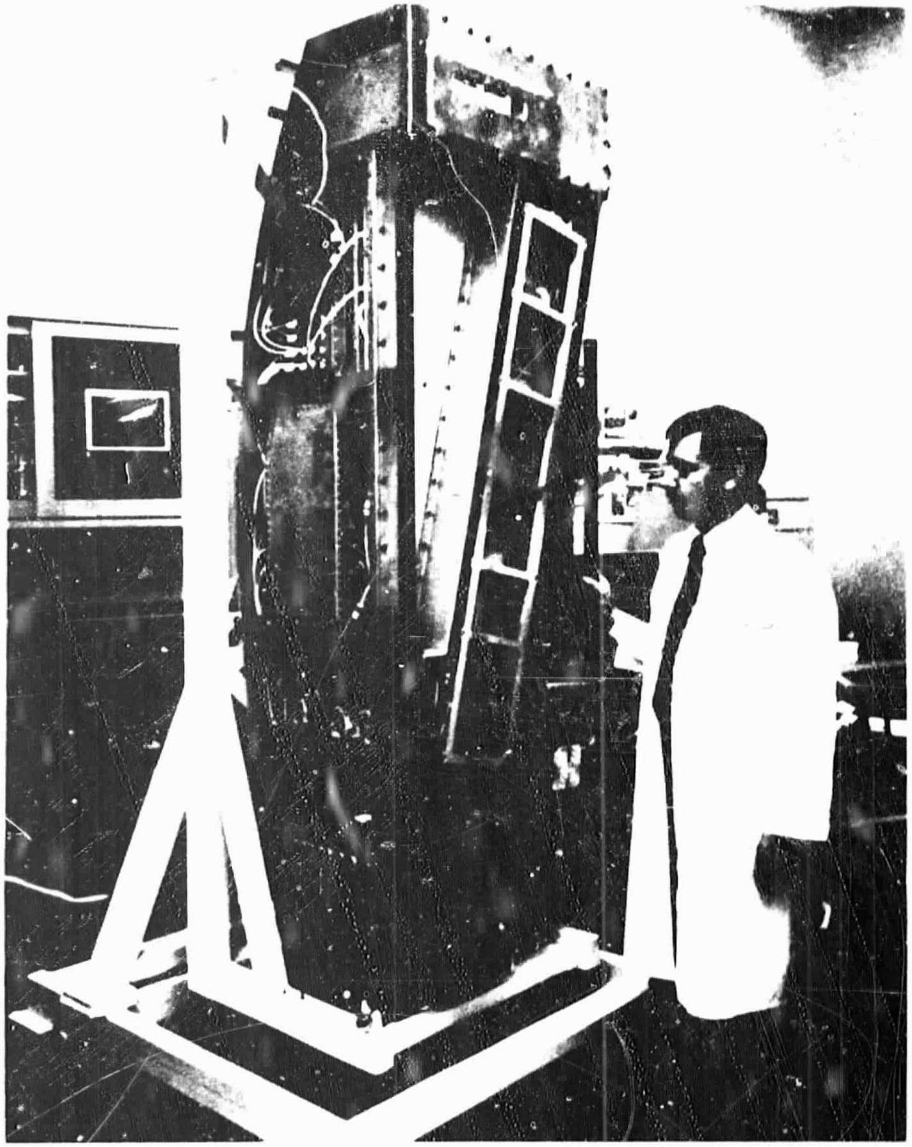
ELECTROPHORESIS OPERATIONS IN SPACE



Flight Dates Under Joint Endeavor Agreement

STS	4	JUN	1982
STS	6	APR	1983
STS	7	JUNE	1983
STS	8	AUG	1983
STS	12	MAR	1984
STS	16	JUL	1984

Results From First STS Flights

1. 500 Times Increase in Yield
2. Quantitatively Repeatable Separation
3. Validated Design Concepts
4. Value of Manned Participation Confirmed

BENEFITS ANALYSIS

12 TYPICAL PHARMACEUTICAL PRODUCTS

The initial market analysis conducted by MDAC prior to embarking on the electrophoresis development program considered many potential products that could utilize the electrophoretic technique (hormones, enzymes, cells, and proteins). The market analysis defined the benefits and needs of each, and sought to identify those products with a uniqueness that could make electrophoretic processing in space a favorable method of production. These analyses led to the identification of the 12 products listed on the facing page, each of which offers significant social and economic benefits to the rest of the world.

The EOS products investigated were found to exhibit varying degrees of demand dependon the market price. For example, while beta cells may offer a one time cure for diabetes, many patients may continue to use insulin as a preventative if the cost of beta cells is prohibitive.

The EOS annual potential patient population indicated on the facing page is probably a conservative (low) estimate. As an example, there are 800,000 emphysema sufferers in the United States. Only 100,000 are considered severe. Our internal economic market analysis for Alpha Antitrypsin considered usage by only 75,000 patients or 75% of the severe sufferers. As this market level is achieved, the production price can be expected to drop and it is possible that many less severe sufferers will consider usage.

The anticipated population benefitting from just the 12 products listed exceeds 17 million persons in the United States alone; the worldwide usage could exceed 250 million individuals per year.

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BENEFITS ANALYSIS
12 TYPICAL PHARMACEUTICAL PRODUCTS

VGB473

Typical Products	Beneficial Medical Application	Function/Status	Annual Patients (USA)
α_1 Antitrypsin	Emphysema	Research Quantities Only Now	100,000
Antihemophilic Factors VIII and IX	Hemophilia	100% Terminal by Age 40	20,000
Beta Cells	Diabetes	Possible Single-Dose Cure	600,000
Epidermal Growth Factors	Burns	Replacement Skin Grafting	150,000
Erythropoietin	Anemia	Replacement Transplants/ Transfusions	1,600,000
Immune Serum	Viral Infections	EOS Provides Higher Purity	185,000
Interferon	Viral Infections	Potential May Be Unlimited	>10,000,000
Granulocyte Stimulating Factor	Wounds	Research Quantities Only Now	2,000,000
Lymphocytes	Antibody Production	Replace Antibiotics/Chemotherapy	600,000
Pituitary Cells	Dwarfism	Currently Not Curable	850,000
Transfer Factor	Leprosy/Multiple Sclerosis	Potential for Other Applications	550,000
Urokinase	Blood Clots	Low Development Costs	1,000,000

STS-4 EOS OPERATIONS SUMMARY

The STS-4 EOS mission is a classic example of the importance of direct manned involvement in a research and development operation. During the two days of operation, a total of 55 operator calls (events) occurred of which 14 (8 on 28 June and 6 on 30 June) were unscheduled. Resolution of these unscheduled events required 62 keyboard inputs to the central processing unit.

Of particular significance is the fact that of these unscheduled calls, five represented malfunctions that, if uncorrected, would have caused the mission to be aborted. Four were process-out-of-range errors and one was a mandatory Stop/Reset/Restart software problem. The presence of an onboard operator provided rapid resolution of these problems and gave a graphic illustration of the value of direct human intervention in maintaining the efficiency of EOS operations.

In the separation process, monitoring of the product stream requires considerable skill on the part of the operator to recognize and interpret the flow pattern. While the use of dye simplifies this task somewhat, such additives may not be desired in processing certain types of products. The bandwidth required to transmit sufficiently detailed real time images of this process to a remote control station would place a heavy burden on the TDRSS or equivalent communication systems and may prove to be impractical in future commercial production operations.

Market projections suggest that the market for EOS products may easily be in the billion dollar range. If even only a fraction of this potential market is captured, the payoff potential is still so high that the premium for mission success mandates the direct involvement of a human operator to protect the initial investment, increase the operational efficiency and to thereby maximize the dollar return to the sponsors of the mission.

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VGB475

STS-4 EOS OPERATIONS SUMMARY

	28 June 1982	30 June 1982
■ Raw Parameters		
• Total Operating Time	6.5 Hr	8 Hr
• Total Number of CPU Operator Calls	27	28
— Scheduled Calls	19	22
— Unscheduled Calls	8	6
• Total Number of Keyboard Inputs Required	99	83
— Scheduled Calls	48	72
— Unscheduled Calls	51	11
■ Averaged Parameters		
• Operator Calls/Hour	4	3
— Scheduled Calls	3	3
— Unscheduled Calls	1	1
• Keyboard Inputs/Hour	15	10
— Scheduled Calls	3	3
— Unscheduled Calls	6	2
• Operator Call Response Time	27 Sec	43.7 Sec

Presence of Man Essential to Reduce Risk of Failure

COMMERCIAL MISSION OPPORTUNITIES

Thirteen commercially oriented missions were included in the MDAC mission model. One of these was a Materials Research Facility for general industrial leasing or service-for-fee operations and the remaining twelve represented typical examples of specific facilities likely to be required by one or more members of the emerging population of potential users. In the judgment of the study team these thirteen missions provided a reasonable representation of the various classes of products and/or services that were identified in the contacts made during the study with potential users.

When discussing the potential of manned and unmanned space platforms with potential users, a concerted effort was made to characterize the potential products or services in terms understandable to the users. The criteria for selecting areas of interest included concentration on products: having a high market value, or having a high value per pound; utilizing the unique properties of space; and having a long enough market life with low enough obsolescence rates that implementation of the research and development activities on a manned space station would be feasible and would allow a sustained production period for recapture of investment.

One or more of forty potential processes, products or services were discussed with representatives of 47 companies and interested organizations.

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VGB461

COMMERCIAL MISSION OPPORTUNITIES

13 MISSIONS IN MDAC MISSION MODEL

CODE	NAME	SOURCE	DATE STAT	DUR	INC DEG
CIR001	MATERIALS RES FAC	MH	I 93	5	A
CMP001	ELECTROPHORETIC PRO	MS	C 90	5	A
CMP002	SILICON RIBBON MAN	MS	C 94	5	A
CMP003	ELECTRONIC CIR ELEM	MH	I 94	5	A
CMP004	MATERIAL MELT/REFORM	B	I 94	8	A
CMP005	ORIENTED MIXTURES	B	I 95	5	A
CMP006	DIR XTAL GROWTH	B	C 95	8	A
CMP007	HI STRENGTH PLASTICS	B	C 97	8	A
CMP008	SEPARATIONS LAB	B	C 94	6	A
CMP009	TOXIC WASTE MONITOR	B	C 92	10	90
CMP010	BIO PROCESSING	B	I 95	5	A
CMP011	MEDICAL FACILITY	B	I 97	10	A
CMP012	GA AS FACILITY	B	I 95	5	

PROCESSES

- Electrophoresi
- Electron Beam
- Containerless
- Oriented Mixtu
- Crystal Growth
- Rapid Tempera
- Unidirectional
- Biomaterials P
- Medical Procec
- Gallium Arseni

TARGET USERS

- AT&T • Monsanto
- Eli Lilly • Fluor
- IBM • Eastman Kodak
- Union Carbide • Nitinol
- Allegheney International
- Johnson Matthey • Eaton
- Calcitek • Staley
- Tucker Anthony • GTI
- DuPont • John Deere
- Bethlehem Steel
- Celanese • MDC
- Hoffmann-LaRoche
- Baxter Travenol
- Inco • Johnson & Johnson
- Ford Aerospace • Comsat
- Microgravity Research
- Geosat Companies

CRITERIA FOR SELECTION

- High Market Value
- High Value Per Pound
- Uses Properties of Space
- Long Market Life — Low Obsolescence Rate

STEPS IN IDENTIFICATION OF USER INTERESTS

The steps followed in contacting potential users and identifying their interests are summarized on the facing page. In identifying the industries and technologies which would be most receptive to new ideas, the primary criterion was that the industry or technology have a strong R&D focus and be on the leading edge of high technology development where the introduction of new ideas is considered routine. With the technology and processes identified, the understanding of what might be done in space could then be developed into the tailored ideas or "seed concepts" for that technology.

As had been the case in previous studies, follow up meetings were found necessary to support the user's development of concepts that emerged from the initial meetings. Without the continuous feedback and interaction provided in the dialog of follow-on meetings, users can easily feel abandoned, and thus less inclined to continue to develop the ground work for space operations. Once there is a "critical mass" of users actively pursuing commercial activities in space, the perception by users that they are alone will lessen and may in fact develop into the competitive race to be first with the best that is so characteristic of our society.

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STEPS IN IDENTIFICATION OF USER INTERESTS

1. Review Prior Work
2. Identify Processes
3. Develop Concepts
4. Develop Target User List
5. Contact Users
6. Follow Up With Discussions
7. Develop Ideas
8. Stimulate Follow-on

RECOMMENDATIONS

- Follow on Efforts to Ensure User Commitments and Produce New Users
- Preserve Proprietary Rights
- Provide Incentives to Support Feasibility Demonstrations Including Access to Manned Space Facilities

KEY FEATURES

- Characterization of Space Attributes for Users
- Use of Seed Concepts
- Protection of Proprietary Concerns

NEW COMMERCIAL PRODUCTS AND PROCESSES

As a member of our study team, Booz, Allen & Hamilton has been very effective in acting as an objective, "third party" interface with some of the candidate mission sponsors and in providing "seed concepts" to stimulate creative thinking for new product opportunities. Their efforts, particularly the investigative work done by Dr. Myron Weinberg, has led to the identification of potential products in several candidate areas. Four of the most promising candidate's areas are summarized on the facing page. In addition, seven other areas were identified which warrant further investigation.

In many cases, there is interest from these potential users in doing materials and processes research in-orbit but a reluctance to speculate about the potential for large scale production of materials and products in space until essential research is completed. This condition could continue until a permanent facility is established in space in which to conduct the research needed to move these products out of the idea phase and into development and pilot production.

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VGB556

NEW COMMERCIAL PRODUCTS AND PROCESSES

OPPORTUNITIES WARRANTING FURTHER INVESTIGATION

1. Gallium Arsenide
   Various Compani
2. Biologically Active
   (Proprietary Com
3. New Plastics Produ
   Celanese Corpor
4. New Biological Pro
   (Proprietary Com
5. Bone Replacement
   Calcitek
6. Metal Reforming
   Nitinol
7. Hazardous Waste Management
   Various Corporat

MOST PROMISING CANDIDATES

PRODUCT	PROCESS	SPONSOR	BENEFIT/ MARKET
■ Iridium Crucibles	■ Containerless Processing	■ Johnson Matthey Inc.	■ Market in Excess of $100 million/yr
■ R&D Laboratory Leasing	■ Various Process Facilities	■ Venture Capital	■ New Business in Excess of $100 million/yr
■ Biological Processing	■ Fermentation	■ Eli Lilly Co.	■ High Value, Health Care
■ High-Performance Catalysts	■ (Proprietary)	■ Venture Group	■ Market in Excess of $100 million/yr

IRIDIUM CRUCIBLE MISSION

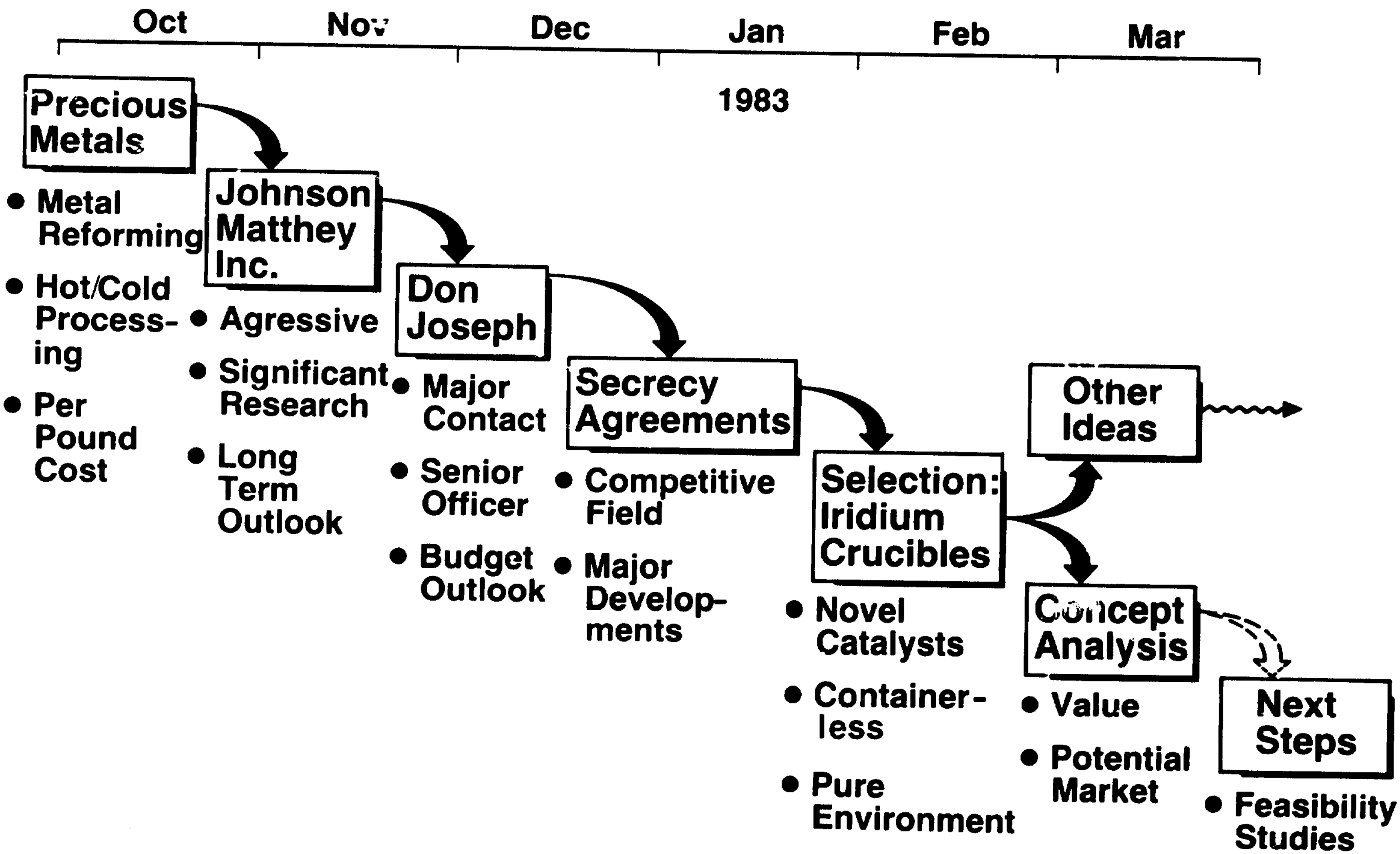
- EXAMPLE OF METHOD AND RESULTS OBTAINED -

An example of the methodology used in identifying and stimulating potential commercial users of advanced space systems is illustrated on the facing page. Examination of the attributes of space prompted consideration by the study team of how metal reforming and unique fabrication may occur. To be cost effective, the selected product or process must involve a high value-per-pound material. Precious metal processing was chosen as a candidate operation in which the high cost of space transportation and processing would be warranted. Johnson Matthey, Inc., was identified as a significant worldwide leader in precious metals processing, with a history of significant commitment to long term product and process development, as well as an aggressive attitude toward growth in new markets. Contact was made through the corporate officer who understood corporate commitment to long term investment: Mr. Don Joseph, Vice President and Treasurer. He, in turn, provided access to the group responsible for new products and development. After negotiation of the confidential terms under which ideas would be exchanged, a meeting was held in which seed concepts on metal working and powder technology were presented. The working group at Johnson Matthey conceptualized an opportunity to use containerless processing in a reaction-free environment to produce purified iridium crucibles. These are used in the production of purified crystals used in advanced information processing systems. The annual market opportunity for these crystals is in excess of $2 billion, with value added of 10% or more if purification through the use of iridium crucibles is possible. Studies to calculate the market and determine the feasibility of processing in space are presently underway.

MCDONNELL DOUGLAS

VGB544

IRIDIUM CRUCIBLE MISSION
EXAMPLE OF METHOD AND RESULTS OBTAINED



COMMERCIAL MISSION SUMMARY

The results of our investigations to date have suggested that significant interest in space facilities can be found among a number of commercially oriented users. The potential market opportunities during the next decade are projected to be in the tens of billions of dollars.

In order to develop and maintain the involvement of potential users, however, space demonstrations will be required and commercial growth or evolution will be highly dependent upon the results obtained in early research and development activities. As evident from the MDAC experience in EOS, the concept to implementation time cycle can easily take 5 to 10 years for the introduction of a new product to a commercial market. Manned facilities will be required especially for the conceptual research and development phases and for maintenance and servicing operations during production or operational missions. An essential requirement for encouraging the growth of commercial markets for space developed products and services is that space facilities be easily accessible by dependable and regularly scheduled transportation systems. Above all, potential users need incentives to remove the "space systems" risk from candidate commercial ventures, the potential for private ownership, guarantees of intellectual property rights, proprietary protection, and access to manned space facilities.

COMMERCIAL MISSION SUMMARY

- New Candidate Users Identified
- Benefits and Market Potential Large
- Followup Essential
- Concept-to-Market Process Takes Years
- Space Research Laboratory Required
- Manned Interaction Essential

Users Need Incentives, Proprietary Protection, and Manned Space Facilities

Requirements on Space Station

- High Power
- Crew Participation
- Continuous Operations
- Pressurized Lab — Vacuum Access
- Microgravity

MISSION DATA BASE

Early in the study the mission data base evolved from a hard copy three-sheet format to a computerized file that was then updated, extended and analyzed as needed throughout the entire study period. The data was collected in the four mission categories--Commercial, Operations, Science and Applications and Technology. The subsets within the categories total 16.

Most of the missions were in the Science and Applications category--reflecting the depth and maturity of the missions planned within NASA. Forty-four parameters were defined for each of 88 missions for the Space Station Mission data. As indicated, these included orbit parameters, accommodation needs, resource requirements, etc.

In addition, a dedicated satellite mission model was also constructed to allow traffic model analyses related to the Space Station and specifically for the OTV studies that were done.

The computerized data base allowed the rapid incorporation of data additions and modifications throughout the study period. In addition, the computational capability allowed the thorough analyses of all ranges and combinations of the many parameters included. The mission data was sorted in various sets according to variations of inclination--four, Space Station needed (required, desired, acceptable), platform needed (required, desired, acceptable) and priority groups--one through four. A total of over 200 complete mission data sorts were accomplished and analyzed.

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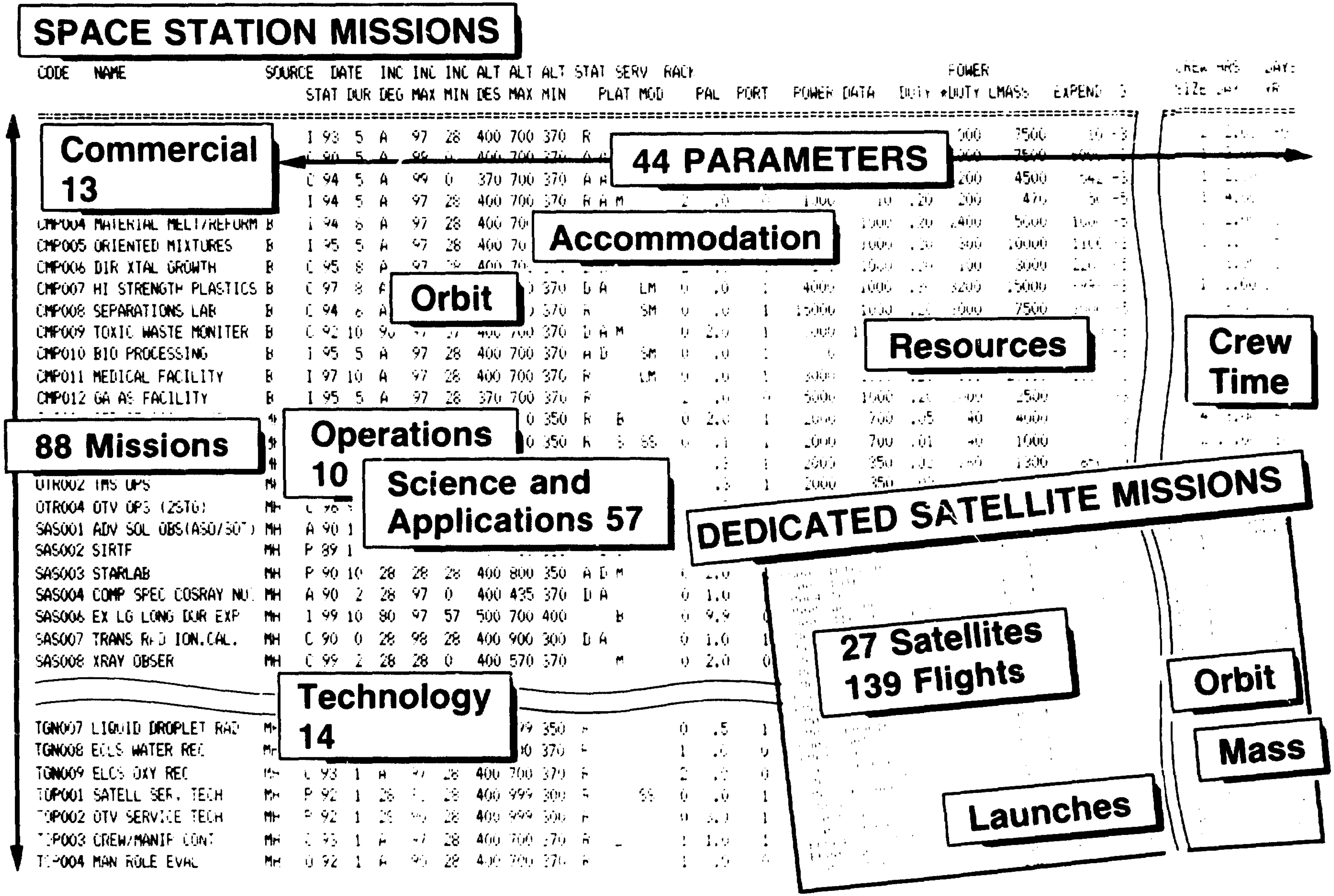
VGB394

MISSION DATA BASE



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BENEFITS AND PRIORITIZATION ANALYSES

The large number of viable missions that are candidates for a Space Station system necessitated that a mechanism be implemented that would allow the orderly accommodation of their requirements.

A benefits/prioritization analyses was conducted to achieve this ordering. A set of 34 parameters were selected that would become measures of the relative benefits of each mission. These included the broad categories of social and economic benefits, cost, constituency and availability. Specifically, each of the 34 parameters was numerically scaled so that each of the missions could be measured to that scale. The relative positions of each mission on each scale were summed resulting in a prioritized list.

As examples, some of the factors included were:

- Demographic data such as the fraction of the population (%) effected.
- Value added in terms of the numeric factor increase in product output on the space mission compared to a non-space solution.
- Cost in terms of procurement costs and also supporting costs; i.e., STS flights and amount of utility resources needed.
- Constituency--the identified support of a real constituency or sponsor group.
- Availability--the relative development maturity, legacy or sponsor planning priority that would indicate not only when the mission might be achieved but also the confidence in it being achieved.

The evaluators were selected from the MDAC study team (including subcontractor and Mission Advisory personnel) for their particular expertise in the areas being evaluated. A total of 12 individuals averaging 25 years experience in space systems analyses were involved, including four with PhDs in the related sciences and one with a doctorate in medicine.

The results have allowed us to select a Space Station system capability versus time that is tailored to the highest priority needs of a comprehensive mission set. In a budget-constrained environment, continued refinement of requirement priorities will be essential.

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VGB825

BENEFITS AND PRIORITIZATION ANALYSES

• SOCIAL • ECONOMIC • CULTURAL • SCIENTIFIC
• TECHNOLOGICAL • COMMERCIAL

34 FACTORS EVALUATED

- Population Affected: U.S., World
- Value Added by Space
- International Appeal
- Cost
- Commercial Value
- Resources Required
- Scientific Value

- Identified Constituency
- Availability

All Missions Analyzed

- 88 Missions
- 12 Evaluators
- 19,652 Value Judgements

Prioritized Missions

PRIORITIZED MISSION MODEL

The results of the Benefits Analysis were used to arrange the mission model into four prioritized groups with Group 1 representing the highest priority. In reality, all of the 88 missions in our model are considered high value, high priority missions since they were synthesized from a candidate list exceeding 400 individual missions. However, this further degree of mission prioritization is necessary for determining the specific capabilities and architectural features that should receive priority consideration in a budget-limited environment. In fact, as is shown in a subsequent chart, budget considerations led to the deferral of some of the accommodation needs for the Priority Group 4 missions.

Our overall objective has been to define an architecture and capability that will be most responsive to the evolving mission needs over the next two decades. This demands a mission model containing representative requirements for the most likely missions to be encountered in this time period. For this reason we recommend a continuing effort to maintain an updated, prioritized mission model.

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PRIORITIZED MISSION MODEL

VGB558

GROUP 1 20 MISSIONS

CMP001 ELECTROPHORETIC PRO
CMP009 TOXIC WASTE MONITOR
OSR001 SAT SERV OPS
OTR001 TMS OPS
SAS001 ADV SOL OBS(ASO/SOT)
SAS009 SPACE TELESC
SAS011 XRAY TIMING EXPL
SAS013 ADV XRAY ASTROFAC
SEP001 SAR
SEP002 MULTISPECT LIN ARRAY
SEP004 PASS MICROWAVE RAD
SEP005 LARGE FORMAT CAMERA
SEP009 LANDSAT D-D'
SEP010 RADAR ALT
SMP003 MATERIALS EXP ASS
TGN005 LRG STRUCT CONSTR
TGN006 FLUID STORE&MANAG
TOP001 SATELL SERV TECH
TOP002 OTV SERVICE TECH
TOP004 MAN ROLE EVAL

GROUP 2 23 MISSIONS

CIR001 MATERIALS RES FAC
OTR004 OTV OPS (2STG)
SAS002 SIRTF
SAS003 STARLAB
SAS004 COMP SPEC COSRAY NUC
SAS015 VLBI
SAS017 GAMMA RAY OBS
SAS020 COSMIC RAY OBS
SCM002 ORB STANDARDS PACK
SEE001 OCEAN PAYLOAD
SEE003 UPPER ATMOS RES
SEE004 SPACE PLASMA PHYSICS
SEE007 ATM DYNAMICS&RAD
SEE008 OP CIVIL MET
SEP006 IMAGE SPECTROMETER
SLS001 PRIMATE EXP FAC
SLS002 PLANT BIO/LS FACIL
SLS003 RODENT EXP FACIL
SLS006 HUMAN EXP FAC
SMP001 MATERIALS PROC LAB
SMP002 MATERIALS EXP CARR
TGN002 ZERO G ANT RANGE
TGN009 ELCS OXY REC

GROUP 3 21 MISSIONS

CMP003 ELECTRONIC CIR ELEM
CMP006 DIR XTAL GROWTH
CMP010 BIO PROCESSING
OAI001 STRUCT ASSY & TEST
SAS007 TRANS RAD ION.CAL.
SAS008 XRAY OBSER
SAS012 SOLAR INT DYNAMICS
SAS014 LAMAR(HTM)
SAS016 LRG DELP REFL
SAS018 HIGH ENER ISO EXP
SAS019 SOLAR COR DYN
SEE002 ATMOS COMP
SEE005 ZERO G CLOUD PHYSICS
SEE006 MET. RES. PKG
SEP007 LUMINESCENCE DET
SEP008 LASER RANGING
SEP012 PLAN SPECT TELE
SEP013 IR SPECT
TGN001 LSS CONTR EXP
TGN004 TETHER DYNAMICS
TOP003 CREW/MANIP CONT

GROUP 4 24 MISSIONS

CMP002 SILICON RIBBON MAN
CMP004 MATERIAL MELT/REFORM
CMP005 ORIENTED MIXTURES
CMP007 HI STRENGTH PLASTICS
CMP008 SEPARATIONS LAB
CMP011 MEDICAL FACILITY
CMP012 GA AS FACILITY
SAS006 EX LG LONG DUR EXP
SAS010 HIRES X&G-RAY SPEC
SCM001 REMOTE SENSING RFI
SCM003 COMM RESEARCH FAC
SEP003 MAG FIELD MAPPER
SEP011 ACT FLUOR SPECT
SEP014 FAR IR SPECT
SEP015 EXTRA SS DET
SEP016 PLANETARY PROC LAB
SLS004 ORB QUARANTINE
SLS005 EXP MED TREAT FAC
SMP004 WAKE SHIELD EXP
SMP005 ULTRAVACUUM FAC
TFM001 LASER COMM&TRACK DEV
TGN003 MATERIALS&COAT TECH
TGN007 LIQUID DROPLET RAD
TGN008 ECLS WATER REC

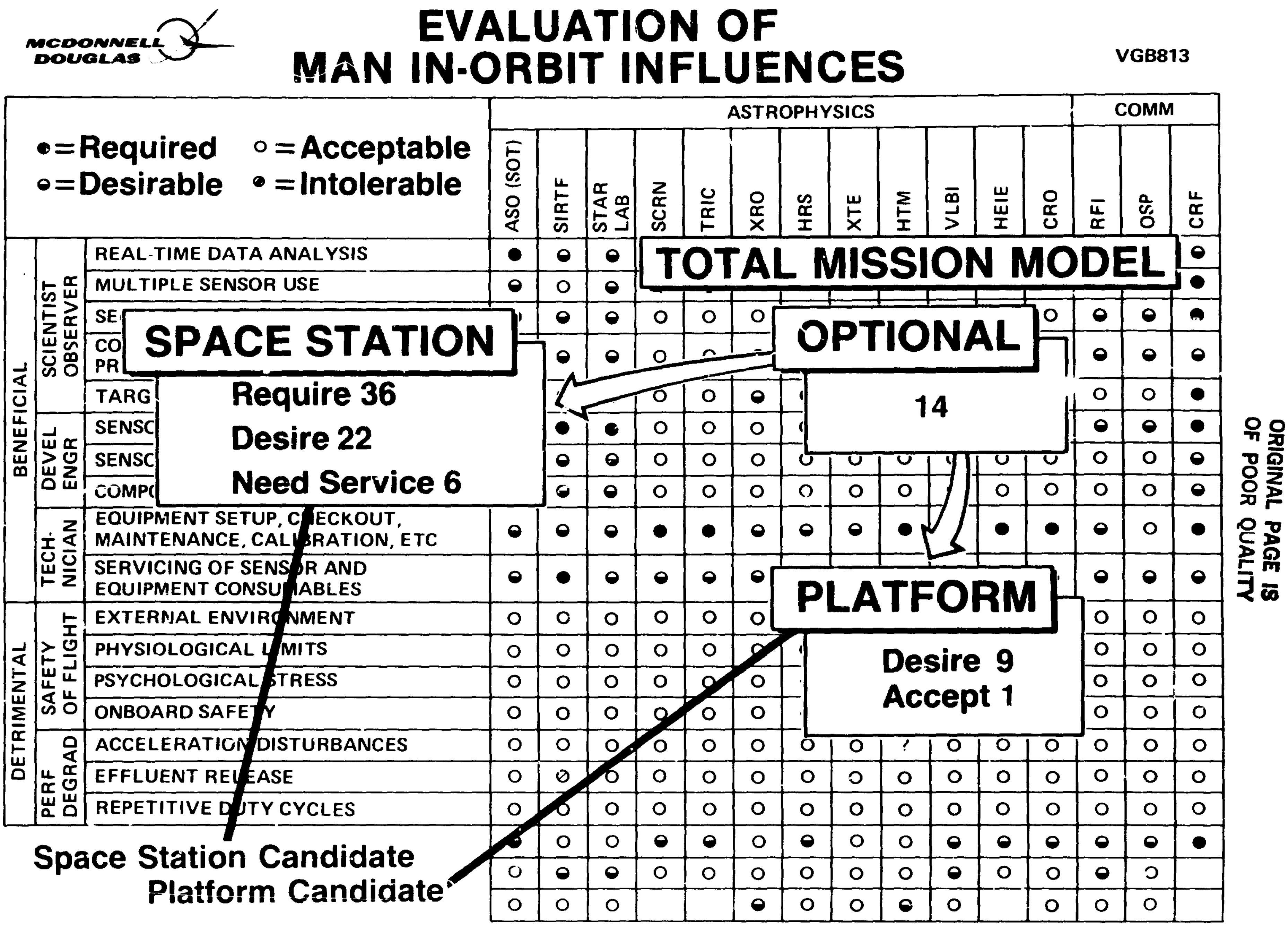
INCLUDES HIGH VALUE MISSIONS

- Commercial Processing
- Satellite Servicing (TMS)
- ROTV Enabling Technology
- Science and Applications (SAR, Xray, SOT, etc.)

EVALUATION OF MAN IN-ORBIT INFLUENCES

All of the 88 missions were analyzed to determine the best accommodation for each in terms of a manned space station, a platform and a dedicated satellite. These were determined at three levels (required, desired and acceptable for each). The required and desired degrees of accommodation are summarized here.

Fifty-eight (36 + 22) of the 88 missions require or desire a space station for accommodation, 10 can best use a platform and 14 can be accommodated by either a space station or a platform. From this data it is clear that a manned Space Station should be a part of the initial system and that a platform should be judiciously placed to augment this basic capability.



MCDONNELL DOUGLAS
EVALUATION OF
MAN IN-ORBIT INFLUENCES
VGB813
●=Required ○=Acceptable
◐=Desirable ⊛=Intolerable
ASTROPHYSICS
COMM
ASO (SOT)
SIRTF
STAR LAB
SCRN
TRIC
XRO
HRS
XTE
HTM
VLBI
HEIE
CRO
RFI
OSP
CRF
BENEFICIAL
SCIENTIST OBSERVER
DEVEL ENGR
TECH-NICIAN
DETRIMENTAL
SAFETY OF FLIGHT
PERF DEGRAD
REAL-TIME DATA ANALYSIS
MULTIPLE SENSOR USE
EQUIPMENT SETUP, CHECKOUT, MAINTENANCE, CALIBRATION, ETC
SERVICING OF SENSOR AND EQUIPMENT CONSUMABLES
EXTERNAL ENVIRONMENT
PHYSIOLOGICAL LIMITS
PSYCHOLOGICAL STRESS
ONBOARD SAFETY
ACCELERATION DISTURBANCES
EFFLUENT RELEASE
REPETITIVE DUTY CYCLES
TOTAL MISSION MODEL
SPACE STATION
Require 36
Desire 22
Need Service 6
OPTIONAL
14
PLATFORM
Desire 9
Accept 1
Space Station Candidate
Platform Candidate
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ORBIT REQUIREMENTS - ALL MISSIONS

The summary orbit requirements for all 88 missions are shown. The largest fraction of them, 33, are independent of orbit inclination and can thus be accommodated at any orbit inclination; the next largest set, 27, require 28.5°. The high inclination requirements are eight at 57°, 10 at 90° and 9 missions at sun synchronous. These numbers of missions accommodated are for the required and desired degree of mission need. Beyond these demarcations the missions have further degrees of acceptability across the entire band of inclination from 28.5° to sun synchronous.

Orbit inclination selections considered these requirements, including their relative degrees of acceptability at other inclinations and the relative cost (Shuttle performance) of achieving each orbit and the location of planned traffic corridors.

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ORBIT REQUIREMENTS -- ALL MISSIONS

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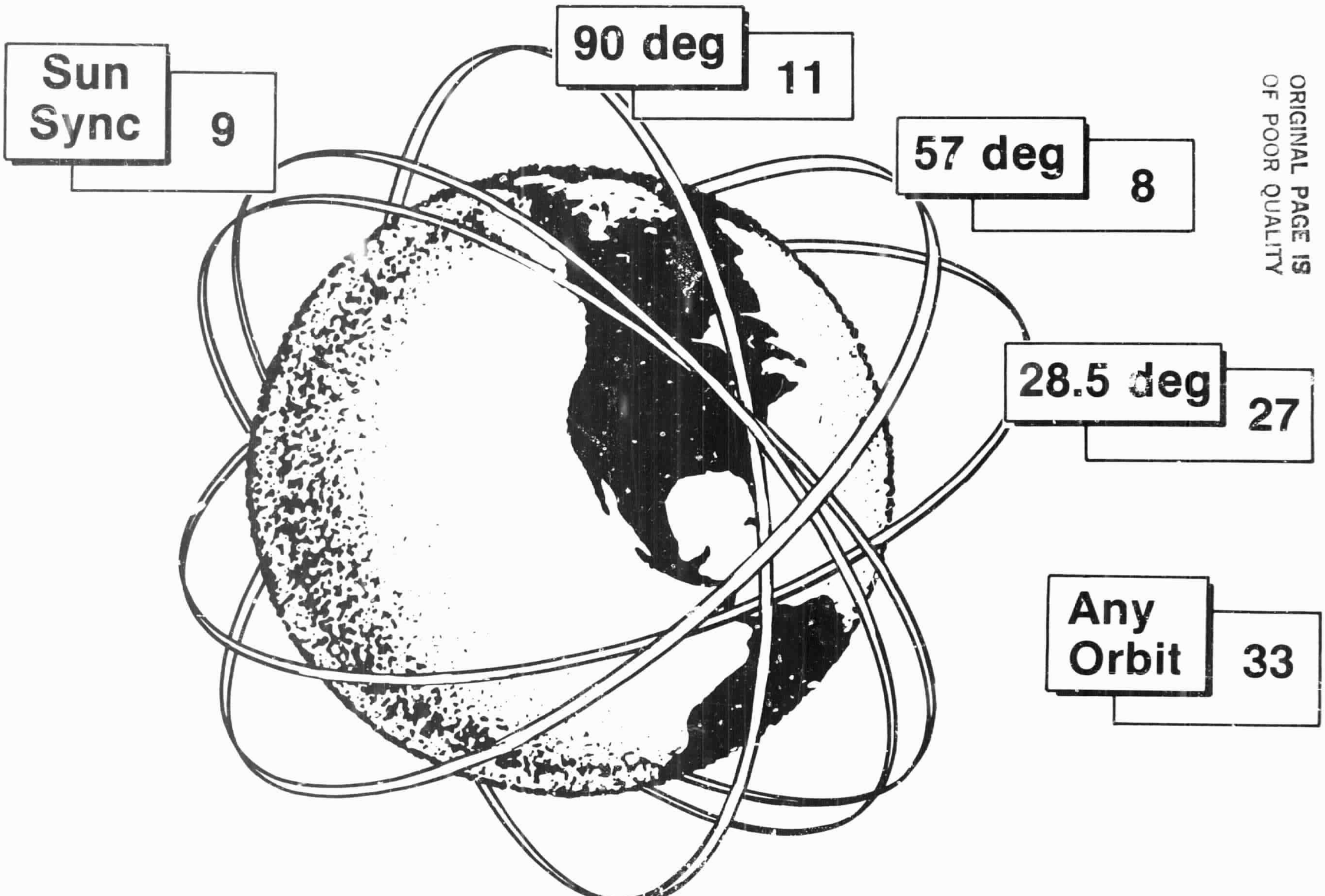

EUROPEAN MISSIONS

A set of 109 missions (104 in low earth orbit) was received from the European consortium late in the study. These were analyzed and their requirements shown here. Compared to the 88-mission set developed on this study, the international missions have a higher percentage of Life Science and related Materials Processing missions. In addition, they are defined at a lower level of detail (i.e., small packages compared to groups of missions) than those developed in the MDAC study. This is indicated by a comparison of the per-mission requirements for power, crew, mass and duration.

The maximum and average values for each mission are much higher for each of the 88 missions defined in this study than for the international missions. The requirements boundaries of the MDAC 88-mission set envelop or include those from Europe. Therefore, the capabilities of the Space Station architecture designed in response to the needs of the 88 missions would be more than adequate to satisfy these basic capability needs of the international missions.

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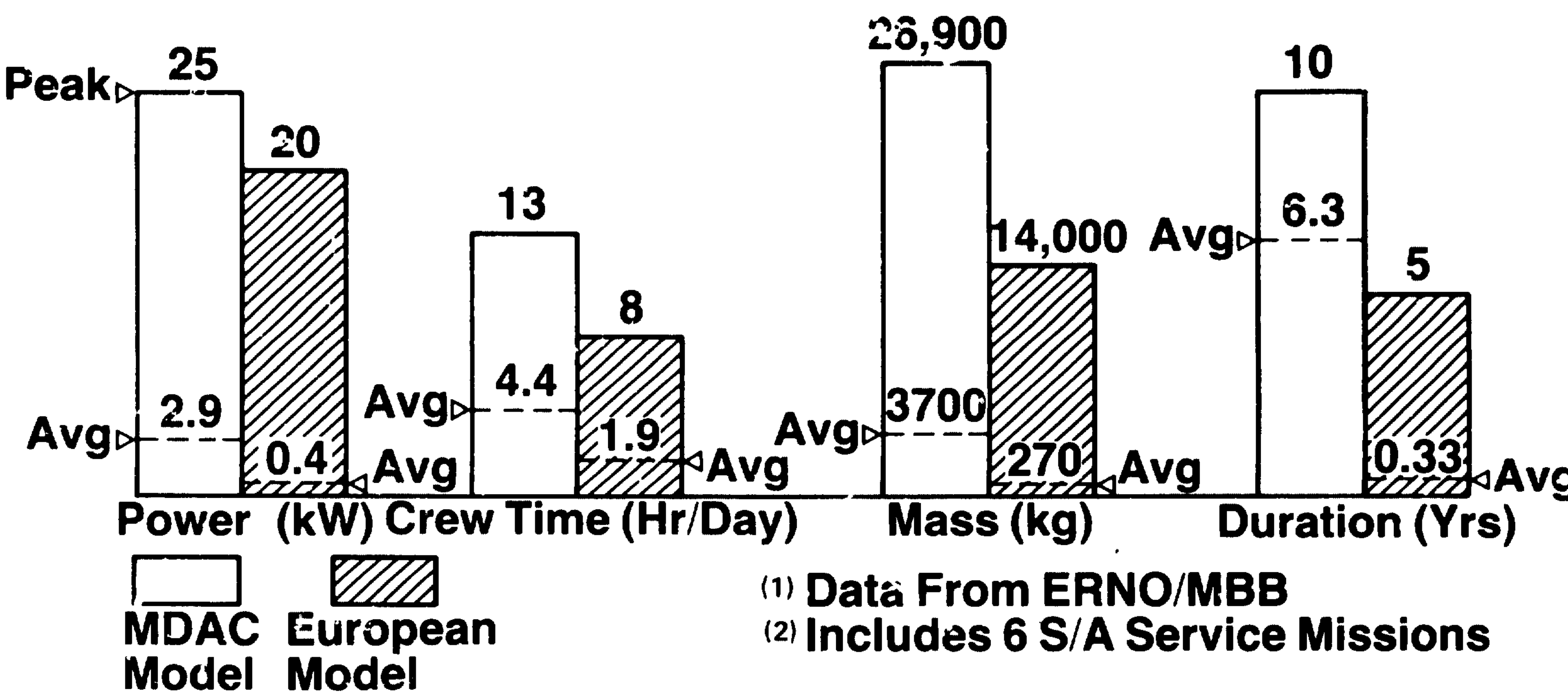
VGB810

EUROPEAN MISSIONS

MDAC Mission Model		European Mission Model (1)	
88 Missions		104 Missions	
Science and Application	57	Science and Application	89
Operations	10 (2)	Operations	4
Technology	14	Commercial Technology	11
Commercial	13		



(1) Data From ERNO/MBB

(2) Includes 6 S/A Service Missions

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ARCHITECTURE OPTION SELECTION

Selection of Space Station system architecture consists of establishing the optimum number, orbit location and implementation date of on-orbit facilities. Manned (Space Station) and unmanned (platform) facility types are considered as well as platforms which may later become intermittently or permanently manned facilities.

Review of mission requirements have shown that all missions identified require inclinations of either 28°, 57°, 90° or sun synchronous. Altitude range is less a driver with most missions accommodated at 500 Km. The mission needs which have a significant impact on the Space Station system are shown in terms of crew size, power, data rate, pressurized volume, number of external berthing ports and resupply requirements.

Selection of the most effective architecture was determined by analyzing various mission scenarios including several levels of accommodation of our prioritized mission model (up to 100%) and on mission emphasis scenarios including science and applications, operations, and technology and commercial. These options were compared based on mission capture capability and cost.

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ARCHITECTURE OPTION SELECTION

ARCHITECTURE VARIABLES

- Facilities
  - Manned Space Station
  - Unmanned Platforms
- Locations
  - 28 deg
  - 57 deg
  - Sun Sync
  - 90 deg
- Sequence of Placement in Orbit
- Capabilities
  - Crew Size
  - Pressurized Volume
  - Power
  - External Ports
  - Data Rate
  - Resupply

MISSION SCENARIOS

1 Prioritized Mission Model

2 Science/Applications Emphasis

3 Operations and Technology Emphasis

4 Commercial Emphasis

EVALUATION CRITERIA

- Mission Accommodation Versus Cost

MISSION ACCOMMODATION

In a budget-constrained environment, it will be essential to achieve the highest degree of mission accommodation for the least program cost. Although the total range of requirements included in our prioritized mission model would demand both manned and unmanned facilities in every major orbit regime, a very high percentage of the total mission set can be satisfied by a single manned Space Station supplemented by a single unmanned platform.

This chart illustrates the accommodation offered by just a few of the architectural options investigated in this study. A single Space Station at 28.5° with an unmanned platform operated at high inclination (preferably sun synchronous or at 90°) offers the best accommodation potential of any two-element, Space Station/platform combination. Sixty-seven missions from our 88 mission model are accommodated with 100% of their requirement needs satisfied. An additional 17 missions receive 75% to 100% of their detailed needs. The total of 84 missions represents a capture ratio of 95% of our 88 mission model. To capture the remaining 5%, plus raise all mission accommodation to 100%, would require additional major facilities in space.

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MISSION ACCOMMODATION

Prioritized Mission Model (88 Missions)

VGB664

Architecture		Missions Accommodated		Total Missions Captured
Space Station	Platform	100%	75%-100%	
28.5°	—	54	10	64
28.5°	57°	57	26	83
	90° or Sun Sync	67	17	84 ← 95%
57°	28.5°	60	18	78
	90° or Sun Sync	65	10	75

ACCOMMODATION OF SPECIAL EMPHASIS MISSIONS

To assess the effects on system architecture, special mission model scenarios were defined emphasizing the mission categories shown. A sample architecture consisting of a single manned space station and a single unmanned platform was evaluated for responsiveness to these mission requirements. The results are as shown.

A space station in high inclination plus a platform at 28.5 degrees offers the best accommodation of the 57 missions in our Science and Applications category. The combined missions in the Operations and Technology categories, including servicing missions for six satellites, can all be accommodated by a single manned space station in low inclination orbit. Commercial missions require primarily an easily accessible, high traffic location (28.5 degrees) plus a high inclination location for Earth survey missions (i.e., 57 degrees or higher).

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VGB551

ACCOMMODATION OF SPECIAL EMPHASIS MISSIONS
SPACE STATION AND SINGLE PLATFORM

☐ Preferred Orbit Location

	Mission Emphasis	Location: Space Station	Location: Platform	Missions/ Accommodated in Emphasis Scenario: 100%	Missions/ Accommodated in Emphasis Scenario: 75-100%	Total Missions Captured
Scenario (2)	Science and Applications (57)	$\boxed{90°}$	$\boxed{28°}$	33	18	51
		57°	90° Sun Sync	28	20	48
Scenario (3)	Operations[1] and Technology (24)	$\boxed{28°}$	Not Required	24	—	24
Scenario (4)	Commercial (13)	$\boxed{28°}$	$\boxed{57°}$	13	—	13

[1] Includes 6 S/A Service Missions

MISSION CAPTURE BY PRIORITY GROUPS

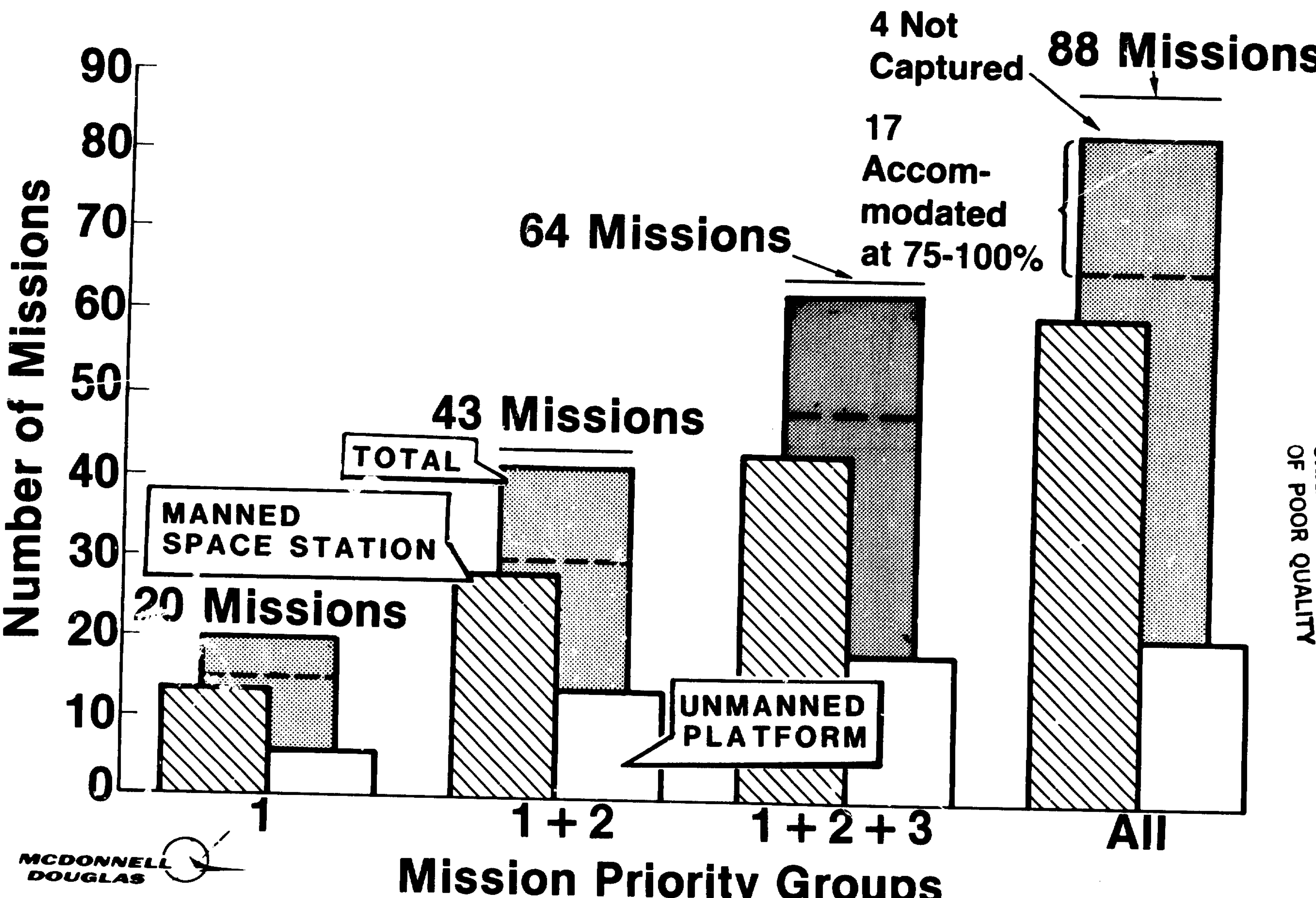
Space Station at 28.5°, Platform at Sun Synchronous

The ability of this architecture to accommodate the prioritized mission model is shown. All 20 of the missions in priority Group 1 can be acceptably accommodated, as can 41 of the 43 in Groups 1 and 2, 62 of 64 in Groups 2, 3 and 4 and 84 of 88 total missions. The four missions not accommodated by Space Station would be allocated to a dedicated satellite. The dashed line indicates the number of missions fully (100%) accommodated in each priority group, i.e., 15, 30, 48 and 67. Those remaining would be dispositioned to dedicated satellites (the four mentioned above) or to the Space Station or platform, thus being acceptably, but not fully, accommodated.

MISSION CAPTURE BY PRIORITY GROUP

VGB391

Space Station at 28.5 deg. Platform at High Inclination



UNIQUE MISSION ACCOMMODATION

The 21 missions not fully accommodated by the 28.5° Space Station and the Sun Synchronous Platform were dispositioned as shown. Acceptable accommodation would be achieved by allocating four of the missions to dedicated satellites, two to the Space Station and nine to the platform. In addition, six missions would be accommodated by redefining them to be split with part of each on both the platform and the Space Station.

This interim solution would be appropriate pending the addition of growth capability at 28.5°, manned presence at sun synchronous, and manned or unmanned capability at 57° inclination.

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UNIQUE MISSION ACCOMMODATION SPACE STATION-28°, PLATFORM-SUN SYNC

VGB668

MISSION		PREFERENCE	
④			
SEP014	FAR IR SPECT	P	28.5
SAS006	EX LG LONG DUR EXP	SS	57
SAS015	VLBI	E	57
SEE003	UPPER ATMOS RES	E	57
②			
SAS001	ADV SOL OBS(ASO/SOT)	SS	97
SAS003	STARLAB	P	28.5
⑥			
TGN003	MATERIALS&COAT TECH	P	28.5
SCM002	ORB STANDARDS PACK	SS	57
SCM003	COMM RESEARCH FAC	SS	57
SEE006	MET. RES. PKG	SS	57
SEP005	LARGE FORMAT CAMERA	SS	90
SEE001	OCEAN PAYLOAD	SS	97
⑨			
CMP009	TOXIC WASTE MONITOR	SS	90
SAS018	HIGH ENER ISO EXP	SS	57
SAS020	COSMIC RAY OBS	SS	57
SEE002	ATMOS COMP	SS	90
SEE007	ATM DYNAMICS&RAD	SS	90
SEP008	LASER RANGING	SS	90
SEP010	RADAR ALT	SS	90
SEP011	ACT FLUOR SPECT	SS	90
SEP002	MULTISPECT LIN ARRAY	SS	97

P — Platform
SS — Space Station
E — Either

INTERIM ACCOMMODATION

Dedicated Satellite

Space Station at 28.5°

Platform at Sun Sync

Growth Accommodations

- Platform 28.5°
  - Manned Station-Sun Sync
    - Platform 57°

ARCHITECTURE ANALYSIS

Data for use in evaluating the architecture options was generated with a computer code developed under MDAC new business funds. This computer tool determines the characteristics of each on-orbit facility required to provide the specified mission support.

Input to the program includes a definition of the facility (architecture) consisting of the technology level of each subsystem, type of facility (manned/ unmanned), number of pressurized and unpressurized ports for mission payloads, resupply period, altitude and unavailable orbiter capability such as launch weight and volume required for the docking module. Mission needs are also input for each year in terms of power, data transmission, volume, crew time, etc.

The computer code determines characteristics for each subsystem in terms of power, data transmission, storage and computation, fixed weight, resupply needs, etc. Packaging and crew volume requirements are also calculated and the total pressurized volume is determined. The number of modules required is then established based on orbiter launch weight or available payload bay volume (which ever is controlling).

Other key characteristics are also determined such as crew size, including housekeeping needs, total array power, heat rejection from integral and deployable radiators and launches for the station, mission equipment and resupply.

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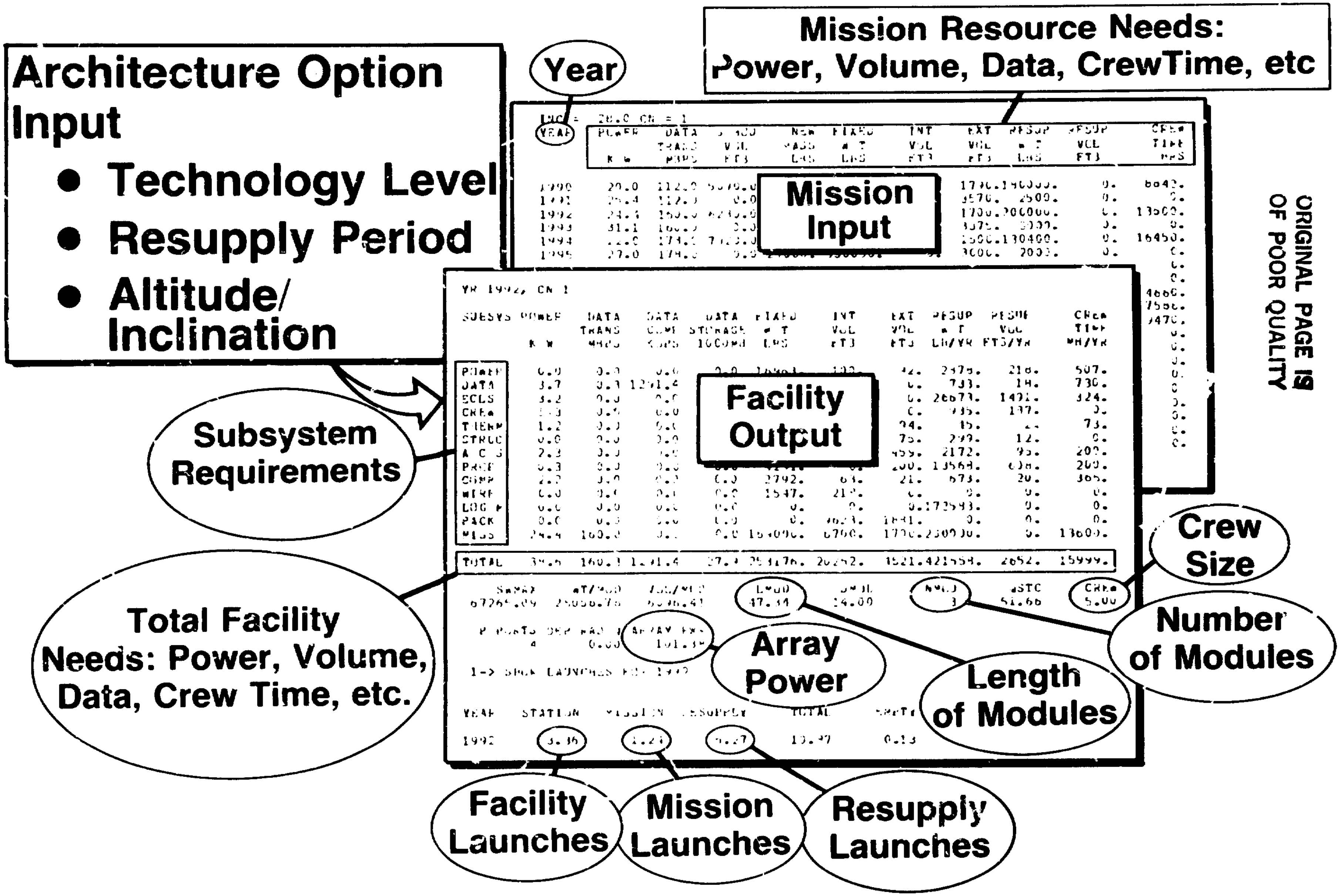
ARCHITECTURE ANALYSIS

VGB683



TIME-PHASED PRIORITIZED MISSION REQUIREMENTS

This chart summarizes requirements from our total mission model for four key architectural parameters: electrical power, data acquisition and transmission rate, crew time and internal pressurized volume. These represent mission requirements only; station housekeeping needs are excluded.

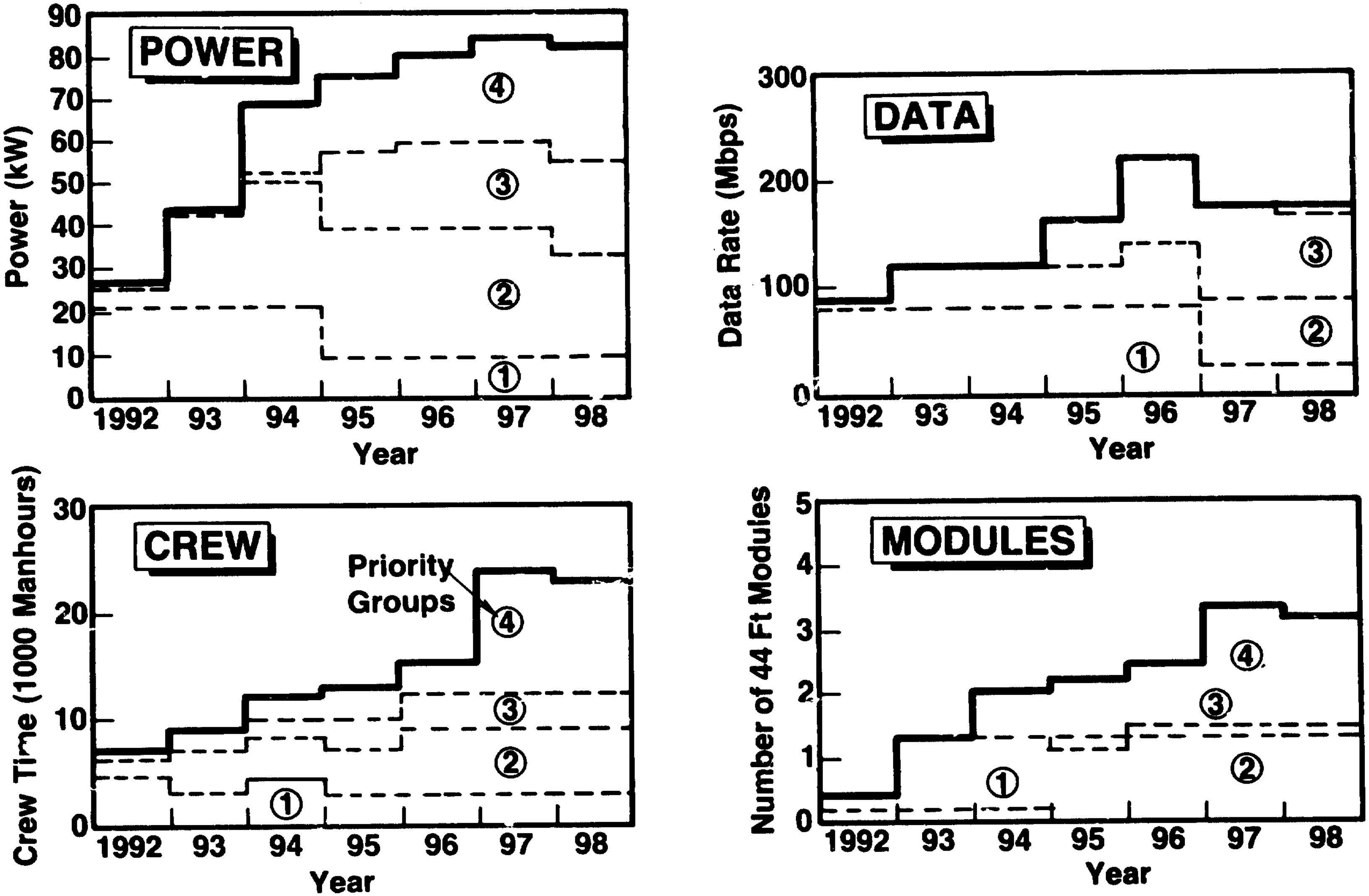
Note that the requirements are summed from the needs of each of our four Mission Priority Groups and that capability buildup requirements are based on the time-phased demands of our mission model.

Power requirements are modest initially but build rapidly to the 70 kW-plus level. Data rate requirements reach the 250 Mbps level, close to the TDRS limit, in mid-decade and are for the high inclination Science and Applications missions. Earlier versions of our mission model indicated even higher data rate requirements with an earlier need date. Crew size is shown in thousands of crew hours per year. Using a 60-hour week, the initial crew size requirement for missions only is less than three and the maximum need is eight. Pressurized module needs are given in terms of equivalent 44-foot long modules. This includes dedicated mission modules plus volume for individual mission installations which share a common module. The requirement is quite small initially because many early missions are of the Science and Applications class which have limited requirements for installations within pressurized areas. In the final architecture, total pressurized volume requirements may be arranged in several modules, perhaps of different lengths, or in compartmented sections of larger modules.

TIME-PHASED PRIORITIZED MISSION REQUIREMENTS
SPACE STATION — 28 deg
PLATFORM — SUN SYNCHRONOUS

MCDONNELL DOUGLAS

VGB817



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TIME-PHASED, PRIORITIZED MISSION REQUIREMENTS
(CAPABILITY OVERLAY)

This chart gives the total requirements for the prioritized mission model with a candidate architecture capability shown with the cross-hatched area. The schedule for this architecture is compatible with budget availabiltiy projections. The architecture provides sufficient resources for Priority 1, 2 and 3 missions except for small deficiencies in power and pressurized modules in the first two years.

In the middle years of the decade, sufficient resources to capture all Priority 4 missions are not provided since these are largely commercial missions which may or may not be required depending on the success of earlier R&D activities. If needed, these large scale production/manufacturing facilities are expected to be operating at profit-making levels and would be privately financed. They might possibly be accommodated on dedicated, separately-funded facilities and receive periodic servicing from the central Space Station.

A 300 MBPS data rate capability is provided for the entire time span in order to minimize the cost of downlinking the data via the TDRSS.

The evolutionary capability step would provide the facilities and resources to accommodate all missions as they mature in the late 1990s.

TIME-PHASED PRIORITIZED MISSION REQUIREMENTS

MCDONNELL DOUGLAS

SPACE STATION — 28 deg
PLATFORM — SUN SYNCHRONOUS

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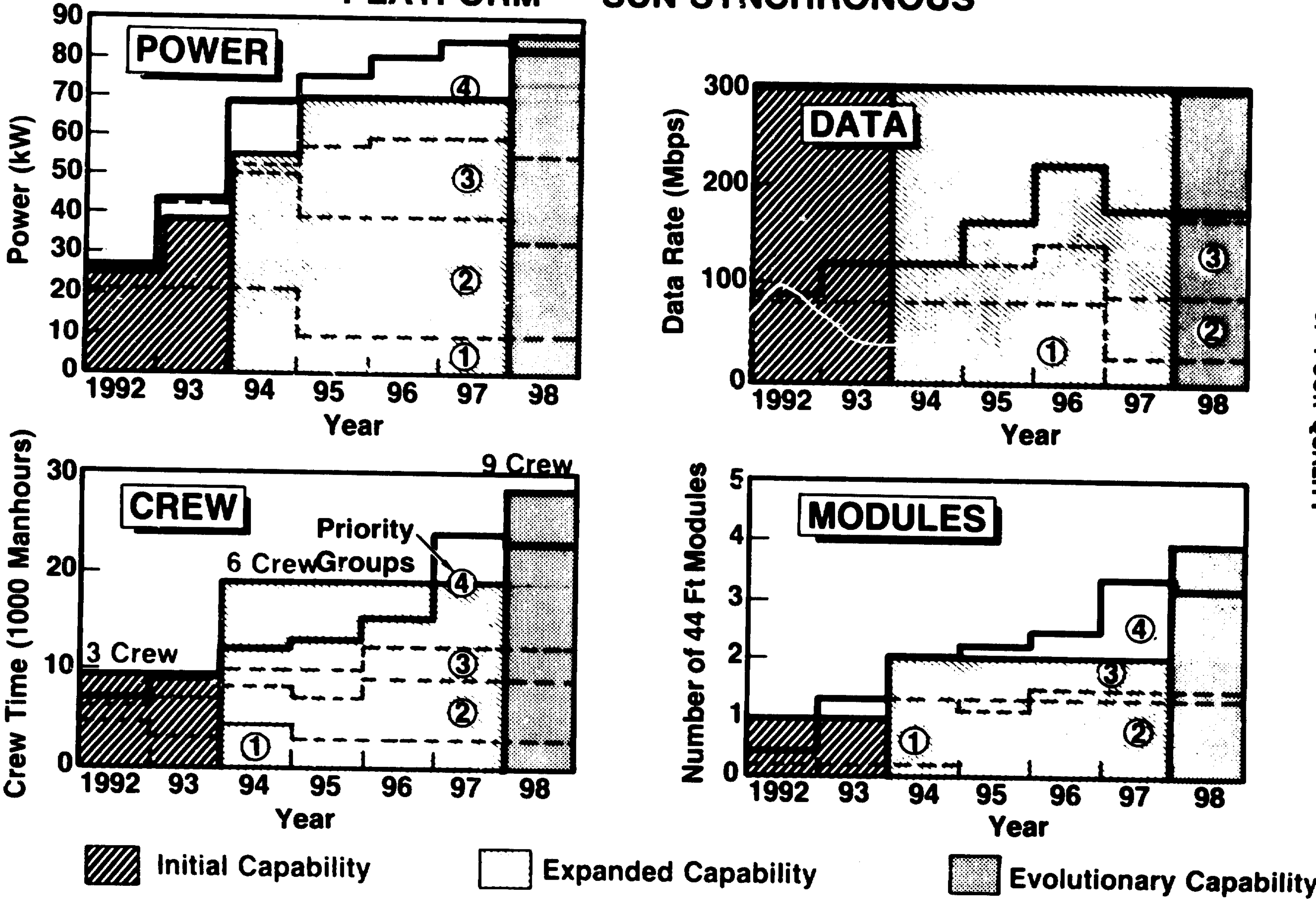

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SPACE STATION SYSTEM ARCHITECTURE

The architecture shown on this chart is responsive to the missions identified in the study while also taking into account anticipated budget rate availability and efficient production rates of Space Station and platform elements.

Initially, this architecture places a four-man Space Station into 28° orbit and provides 25 kW to payloads. This will be primarily an R&D facility supporting science and applications, operations and technology development and early commercial missions, such as an EOS early production facility. EMUs and MMUs will be provided for general purpose EVA tasks.

After about a year, a small platform will be placed in sun synchronous orbit primarily to support science and application missions requiring full earth surface coverage. This platform will provide about 15 kW to payloads and a high data rate of 300 MBPS. A data rate of 250 MBPS is required by some payloads, however efficient use of the TDRSS dictates the 300 MBPS data rates.

The Space Station at 28° will be expanded in about 1994 to an eight man crew and 40 kW for the missions. Also, a crane, TMS and TMS servicing will be added between 1992 and 1994 to retrieve and service satellites. This addition of resources is necessary as the role of the Space Station emerges from primarily an R&D facility to an operations and commercial endeavor. This process is expanded in 1995 when a platform is launched into a 28° inclination providing additional amounts of power (15 kW for missions) to provide a relatively benign atmosphere for material processing and commercial production facilities. This platform will also provide for science and applications missions desiring the lower inclination orbits.

In the 1996 time frame, the Space Station is expanded once again to provide ROTV support. The facility at this point in time will support a wide base of R&D, early commercial development and operations support.

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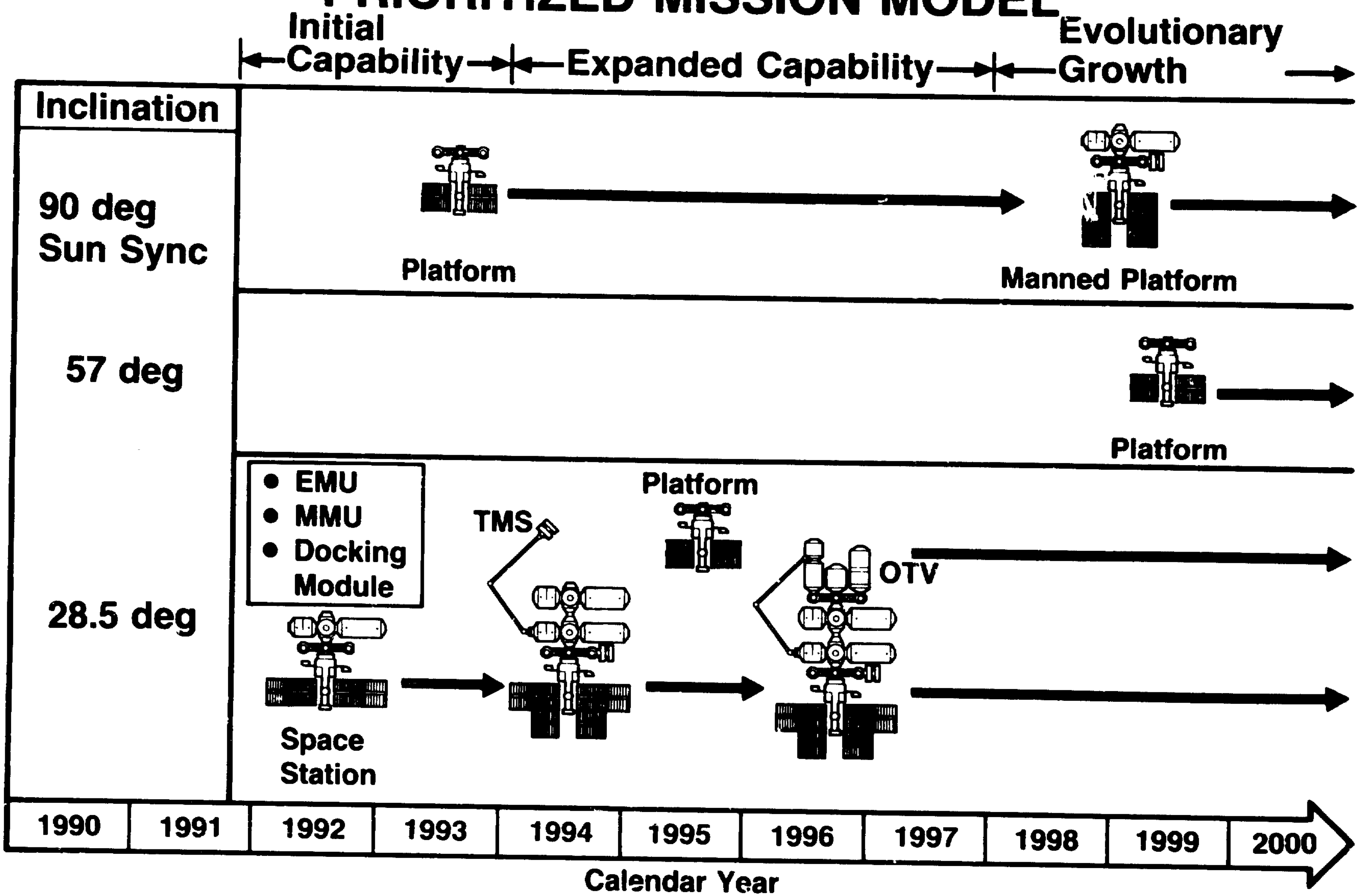
SPACE STATION SYSTEM ARCHITECTURE PRIORITIZED MISSION MODEL

VGB553A



ARCHITECTURE BUILDUP SEQUENCE

PRIORITIZED MISSION MODEL

The baseline architecture's buildup is accomplished through seven separate steps which either add new facilities or expand facilities already deployed. Standard sized modules and elements are used in these steps as indicated below.

1. Space Station at 28°
   - 4 man crew (3 for missions)
   - 25 kW mission power

2. Platform at 97°
   - 15 kW mission power
   - 300 Mbps data rate

3. Expand Space Station
   - 8 man crew
   - 40 kW mission power

4. Platform at 28.5°
   - 15 kW mission power

5. Expand Space Station at 28°
   - Add ROTV operations

6. Expand platform at 97° (evolutionary growth)
   - 4 man crew
   - 25 kW mission power

7. Add platform at 57° (evolutionary growth)

8. Continuous logistics and assembly-level upgrade.

VGB539

ARCHITECTURE BUILD-UP SEQUENCE

PRIORITIZED MISSION MODEL

- Initial Manned Space Station at 28.5°
- Platform at Sun Sync
- Expand Space Station at 28.5°
- Platform at 28.5°
- Add ROTV Capability to 28.5° Space Station
- Add Fully Manned Capability to Sun Sync Platform
- Add Platform at 57°

MODULAR GROWTH ESSENTIAL

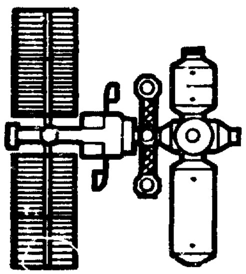
Through the correct use and proper design of standard modules for both Space Station and subsystem buildup, overall program costs and schedule can be reduced. The cost of design, development and qualification of the first article of a design can be from 3 to 15 times the cost of a second identical article. The illustration shows an initial capability Space Station using six modules. The facility is then expanded in two steps to reach the expanded capability space station by modular duplication in the electrical power subsystem, adding a second habitat module, laboratory module, docking module and payload support structure, and by adding new elements for the OTV and satellite servicing operations. The growth facility, with increased electrical power crew and pressurized volume, can capture 100% of the missions assigned to the facility orbit location.

MODULAR GROWTH ESSENTIAL

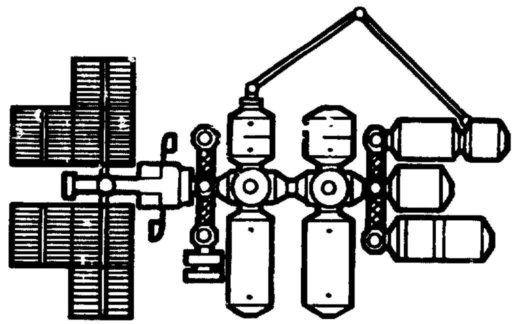
DRIVERS

- Limited Annual Budget
- Requirements Evolving
- Missions Escalate
- Minimizes Non Recurring Costs
- Packaging for Orbiter Transport

→ At Assembly Level and Subsystem Level



GROWTH →



INITIAL CAPABILITY SPACE STATION
• 25 kW Payload Power • Mission Crew of 3 • Pressurized Vol 12,000 ft^3

EXPANDED CAPABILITY SPACE STATION
• 40 kW Payload Power • Mission Crew of 6 • Pressurized Vol 21,000 ft^3 • TMS • OTV • RMS

DATA SYSTEM ARCHITECTURE

The data system architecture selection will have a major influence on the Space Station user support effectiveness, flexibility, growth capability, and life cycle costs. Many communication paths are possible to provide data and control links between the ground-based system users, the onboard crew, and the in-orbit systems.

A Space Station provides unique data system opportunities as well as challenges. The Space Station's features allow it to be used as a data concentrator; that is, it can collect, buffer, and process data from platforms, free-flyers and attached payloads and transmit the collected data or processed data products to the ground-based user. This can greatly improve the utilization efficiency of the communication network (TDRSS, NASCOM, etc.) by concentrating the data communication into short, high-rate bursts. Direct links to a user facility or discipline center (e.g., solar astronomy, life sciences) are more feasible with a Space Station because of its power, weight, and volume capability. These direct links enhance user autonomy and privacy and unload the NASA communication networks and data facilities.

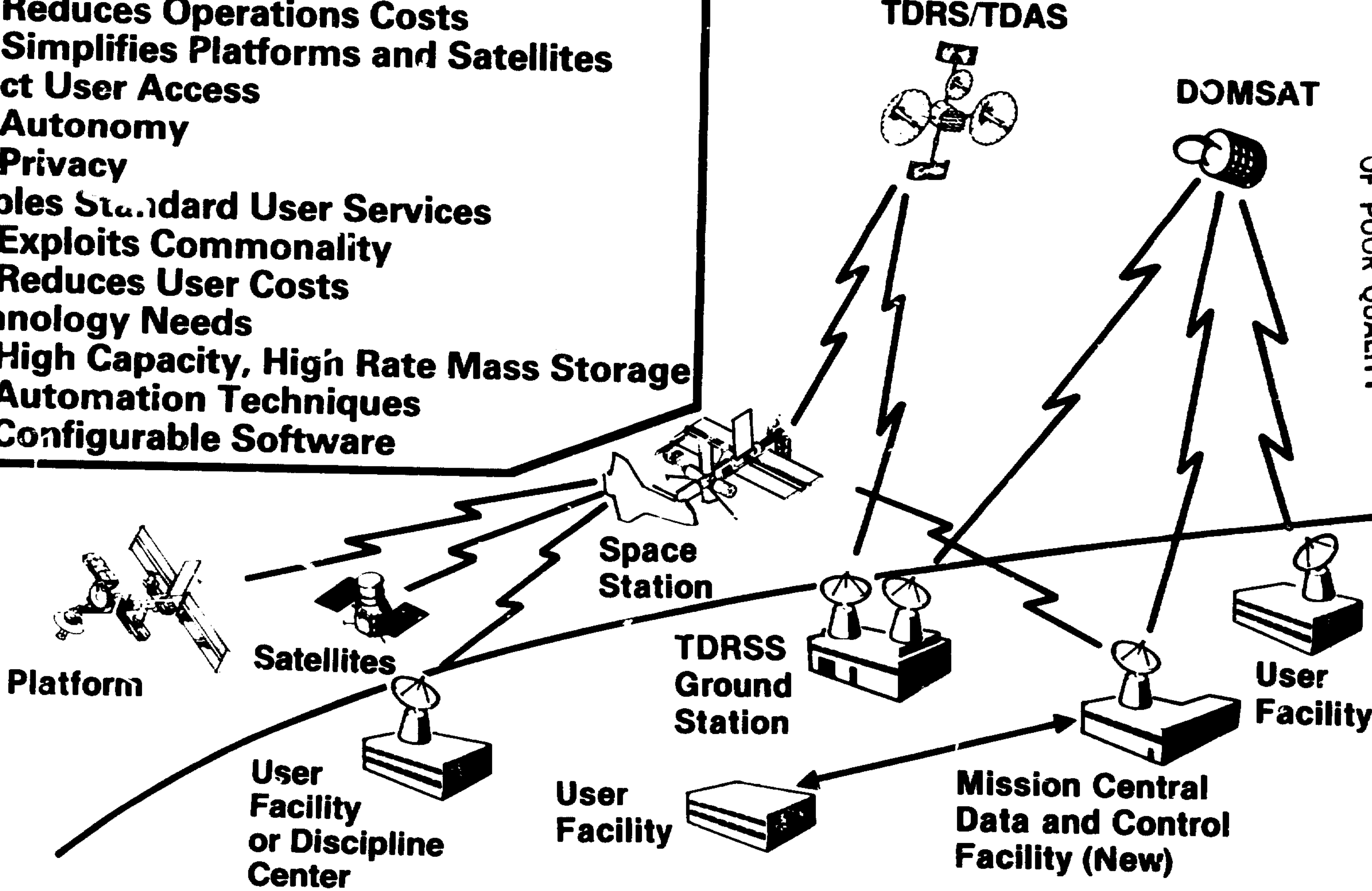
Standard services and interfaces are important to reduce user costs and to simplify the integration of user systems into the Space Station system. Some important technology development that will be needed to support the data system architecture is advanced mass storage devices to support the Space Station data concentrator function and to support ground data capture and archiving. Automated techniques, both in-orbit and on the ground, and reconfigurable software will contribute to reducing system operating costs.

DATA SYSTEM ARCHITECTURE

VGB546

Space Station:

- Data Concentrator
  - — Improves TDRSS Efficiency
  - — Reduces Operations Costs
  - — Simplifies Platforms and Satellites
- Direct User Access
  - — Autonomy
  - — Privacy
- Enables Standard User Services
  - — Exploits Commonality
  - — Reduces User Costs
- Technology Needs
  - — High Capacity, High Rate Mass Storage
  - — Automation Techniques
  - — Configurable Software



PROGRAM DEFINITION COST MODEL

The primary tool for determining Space Station Program cost and funding requirements is the MDAC computerized space facility cost model. It is an efficient tool for estimating the cost of space facilities (e.g., Space Station, platforms, TMS, etc.) and determining the aggregate annual funding requirements for program architecture alternatives. In the case of the Space Station facility, cost estimates are built up from the element level. Development, production and operational costs are calculated for the specified facilities. Program costs are accumulated for the combined facilities and annual funding requirements determined according to the scheduled sequence of facility starts. These requirements are tested against input NASA budget allowances and discrepancies may be rectified by reloading the annual funding level if desired. Allowance is made for NASA integration and management and a 30 percent contingency. The level of commonality between succeeding facilities/elements may be specified. Provision is made for altering technology levels at the element level.

MCDONNELL DOUGLAS

VGB499

PROGRAM DEFINITION COST MODEL

ORBIT: 235
INCLINATION: 28.50 DEGREES
NO. MODULES = 4
NO. 2 DIA MODS=0., NO. 1 DIA MODS#1=1., NO. 1 DIA MODS#2=1., CREW SIZE= 4.
THERMAL LOAD= 51.0, DATA RATE= 80.0, NO. DOCK MODS= 1.
NO. PAYLD SUPPORT STRUCT= 1., NO. SHRT MODS= 0., BUS POWER= 38.0
ATP= 1-86 IOC=192 EOC=400
TOTAL FACILITY COST=5214.683852907

	TOTAL FACILITY	TOTAL TRANSP	CUM ARCHITEC OPTION	OVER/UNDER NASA BUDGET	CUM TRANSP
198			0.000	0.000	0.000
198			0.000	0.000	0.000
198			0.000	0.000	0.000
198			3?2.000	.000	0.000
198					
198					
198					
199					
199					
199					
1993 =	185.148	48.597			
1994 =	185.148	48.597			
1995 =	185.148	48.597			
1996 =	185.148	48.597			
1997 =	185.148	48.597			
1998 =	185.148	48.597			
1999 =	185.148	48.597			
2000 =	185.148	48.597			
TOTAL =	6695.868	725.176	6695.868		

INPUT

- Space Facility
  - Facility Type
  - Sizing Parameters
  - Programmatic Data
- Budget Ceiling

OUTPUT

- Facility and Architecture Costs
- Annual Funding Requirements
- Operations Costs (STS, Resupply)
- Over/Under Budget

SPACE STATION PROGRAM FUNDING

Program funding requirements for the architecture necessary for maximum accommodation of the prioritized mission model are shown. The annual funding is constrained to a maximum of $1.37 billion (1984 dollars). Cumulative facility costs are shown, with factors to account for NASA management and a 30% contingency included. An initial capability station, sized to accommodate four crew persons, is estimated to cost $5.2 billion. An expanded capability would include station growth from four to eight persons and introduction of TMS operations. Total cost for these additions is $1.2 billion. If ROTV development and operations were introduced, an added cost of $0.8 billion would be incurred. Funding for operations is overlaid, including consideration of the costs of spares and ground support. The cost of STS operations is excluded.

VGB818

SPACE STATION PROGRAM FUNDING PRIORITIZED MISSION MODEL

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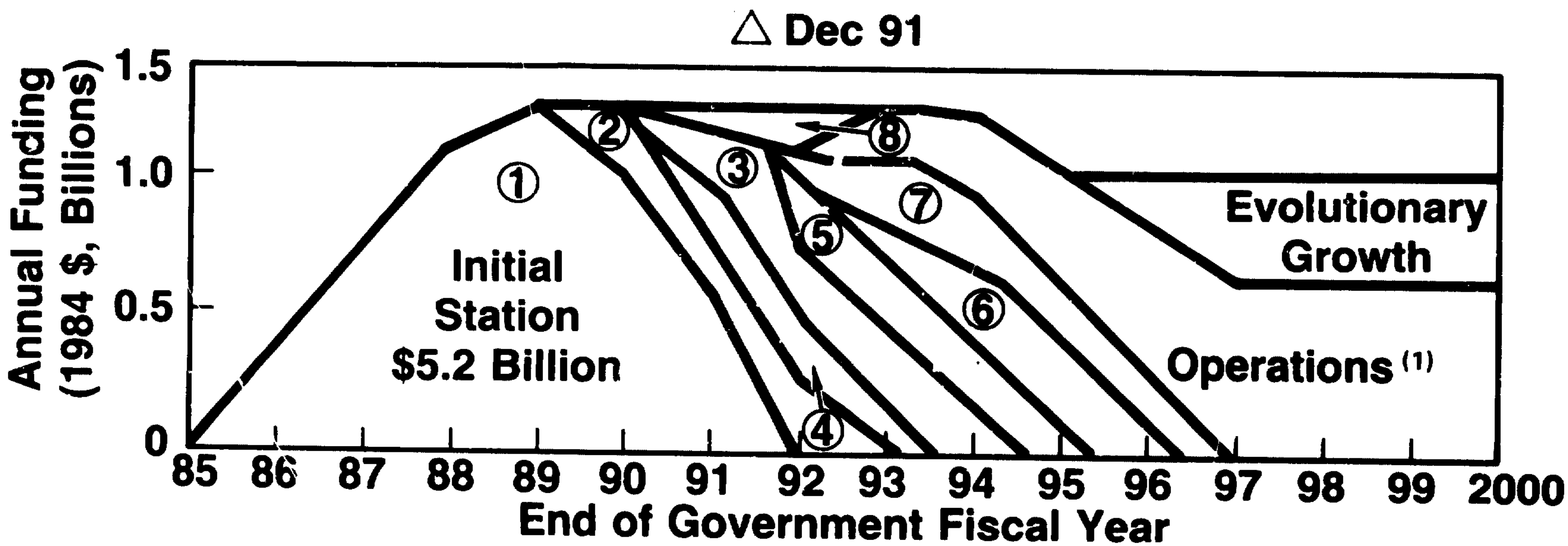
① Initial Space Station △ Dec 91
② Platform 1, $1 Billion △ Dec 92
③ Space Station Growth, $1.2 Billion △ Dec 93
④ Teleoperator (TMS), $0.3 Billion △ Oct 94
⑤ Platform, $0.5 Billion △ Dec 94
⑥ Space Station Growth, $0.8 Billion △
⑦ Reusable OTV, $1.3 Billion △ Oct 96
⑧ Ground Support Equipment, $0.2 Billion



(1) Excludes STS Costs

ARCHITECTURAL OPTIONS

This chart shows the architectural elements and relative cost for three levels of mission capture of the prioritized mission model. The mission model which captures 50% consists of a Space Station at 28° inclination and a platform at 90° inclination and employs a TMS for satellite servicing and Ku band communications as required by some high priority science and applications missions.

In order to capture the 75% model, missions of lower priority (primarily group 3) are added. Growth subsystems and an RMS are required to capture this 75% model.

Capture of the 95% model requires the addition of another 28° inclination platform and an OTV to satisfy operations missions launching payloads to geosynchronous orbits.

The costs show that the 50% capture costs a factor of .65 compared to a factor of 1.00 for 95% capture. This means that the cost is greater per mission captured for facilities with reduced capture. Also, a smaller increase in cost occurs between the 50% and 75% than between the 75% and 100% capture. This is primarily due to the need for the OTV for the 95% capture version.

ARCHITECTURAL OPTIONS

Mission Model		ARCHITECTURAL ELEMENTS							COST VS CAPTURE		
		Space Station	Platform	TMS	OTV	RMS	Ku Comm	Subsys Growth	50%	75%	95%
Prioritized Missions	50%	●	●	●			●		0.65		
	75%	●	●	●		●	●	●		0.70	
	95%	●	● ●	●	●	●	●	●			1.00(1)

(1) 1.00 Represents Total Program Cost — Prioritized Mission Model

CONCLUSIONS

The 88 missions selected for our model are representative of the hundreds of high value mission candidates that exist. To derive the most effective system architecture in a limited budget environment will require careful selection and time-phasing of the capability buildup. For this reason, some form of mission prioritization is mandatory. Our investigation confirms that many opportunities for new commercial products and services exist but the development of these opportunities will require access to permanent manned facilities in orbit where complex R&D activities can take place. The benefits to be derived from the identified commercial, scientific, operational and technological missions will have far-reaching impacts on our economy, the health and welfare of our people, our status in world leadership and our technological readiness for the future.

The architectural concept for the Space Station system must address the need for both manned and unmanned facilities in various orbit locations. It must also be adaptable to changing mission requirements and priorities and to realistic budget constraints. A modular concept with multi-use elements can be devised that will provide this flexibility. The first facilities in orbit should focus primarily on research and development objectives tha can accelerate our rate of progress across a broad front of high technology pursuits.

Our assessment of program costs is based on 20 years of experience with manned space systems. As the principal contractor on Mercury, Gemini and Skylab, and as a major participant in almost all manned space station conceptual studies conducted in the U.S. to date, McDonnell Douglas has confidence that a Manned Space Station Program of affordable cost will prove to be a worthy investment and will contribute greatly to our technological advancement and position as a world leader. By structuring our space capability to evolve as our needs and priorities change, we will maintain the cost-effectiveness of our investment.

MCDONNELL DOUGLAS

VGB689

CONCLUSIONS

Mission Needs

- Mission Prioritization is Mandatory
- Candidate Commercial Users Exist
- Far-Reaching Benefits

Space Facilities

- Manned Facility is Essential
  - To Commercialization
  - To Operations and Technology
- Candidate Architectures Need:
  - Modular Design
  - R&D Lab First
  - Platforms to Supplement Manned Station

Costs

- Program Costs Are Affordable
  - Evolutionary Build-Up Essential
  - Benefits Repay Investment

MAJOR RECOMMENDATIONS

The results and findings of this study provide valuable guidance for the next phase of Program Definition. These recommendations are offered:

1. The methodology used by the McDonnell Douglas, Booz, Allen & Hamilton team, has been successful in locating and stimulating interest in several commercial companies representing new space product and service ideas. We should maintain this effort on a continuous basis. We encourage NASA to establish a permanent, high level, Commercial Mission Development Office as a focal point for user inquiries and interaction leading to future missions. At the earliest opportunity we will need to formulate specific concepts for industry participation in the Space Station Program including the definition of resources to be available and the costs to the users.

2. The next phase of effort will be critical to establishing the system framework for an efficient, high return-on-investment program. We recommend that the maximum resources be focused on the top-level requirements and the system and operational issues shown on this chart. Selective R&D should focus on current technology limitations where these limitations constrain performance, mission accommodation or affect operating cost, efficiency, reliability and safety.

3. As we move into concept definition and preliminary design, we recommend maximum emphasis on subsystem and assembly level modularity with the selection of technology options and system capability to be driven by a realistic set of budget assumptions and a "design to cost" approach.

4. As we begin to transition to the Space Station era, our planning and development of mission equipments should consider their ultimate use within the Space Station system. Current limitations in Shuttle mission duration and power available for payloads severely limits its use in bridging the time gap as we await the availability of a permanent manned Space Station. Consideration should be given to the value to be derived by extending these Shuttle capabilities and offering interim solutions to the growing backlog of high value mission objectives. The adjacent chart also lists some of the key Space Station system and operational issues recommended for high priority attention at a detailed level in the next phase of investigation.

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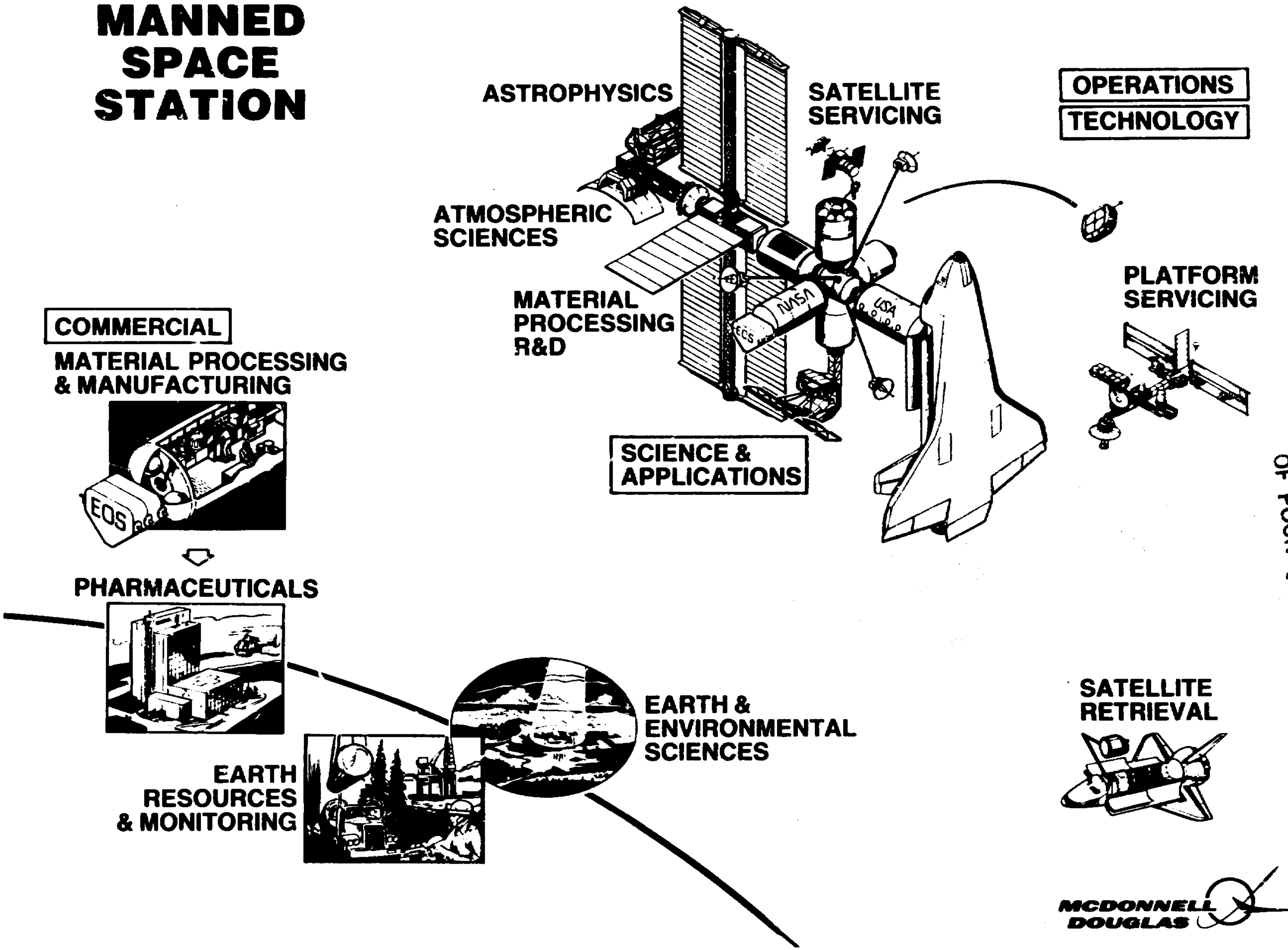
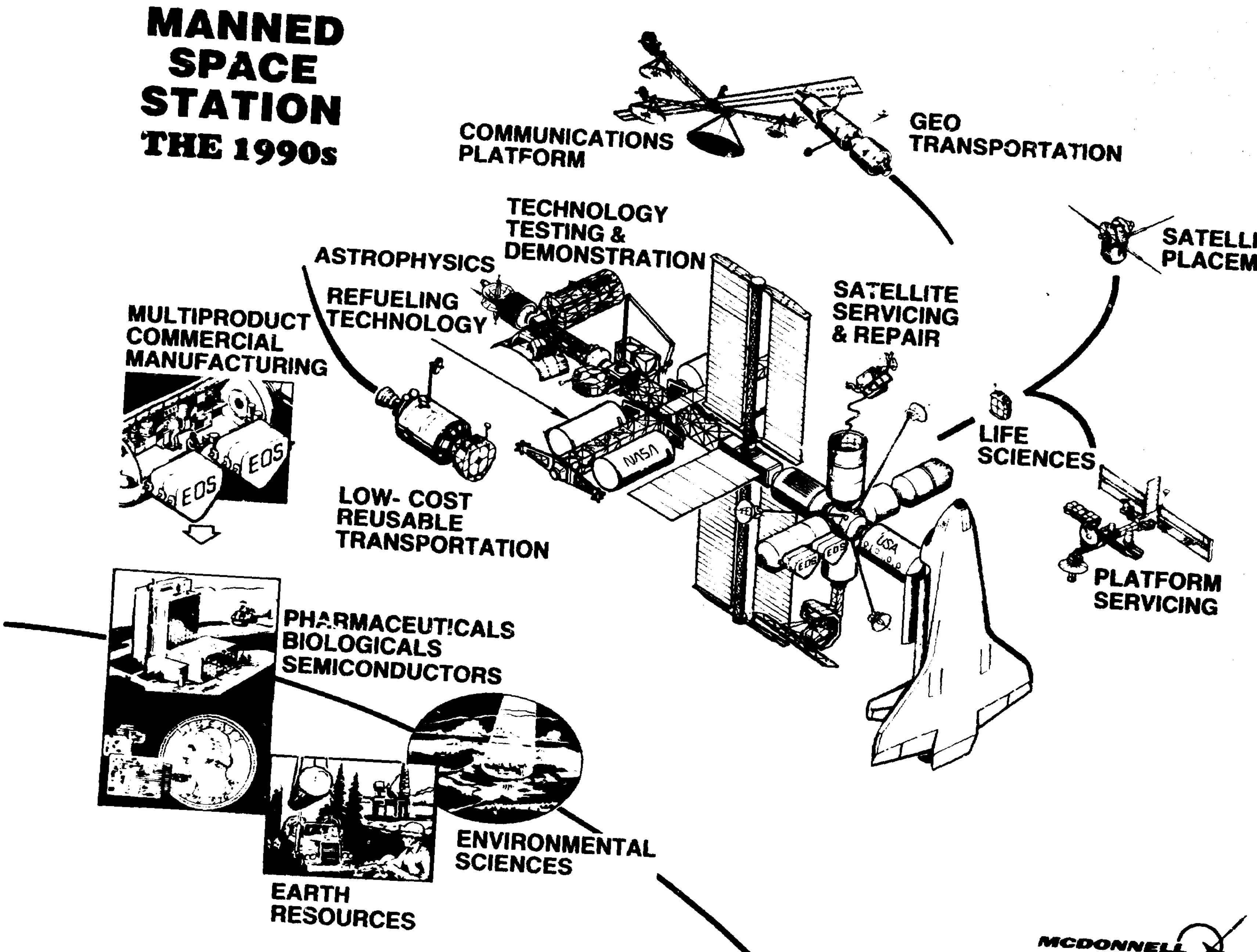
VGB550

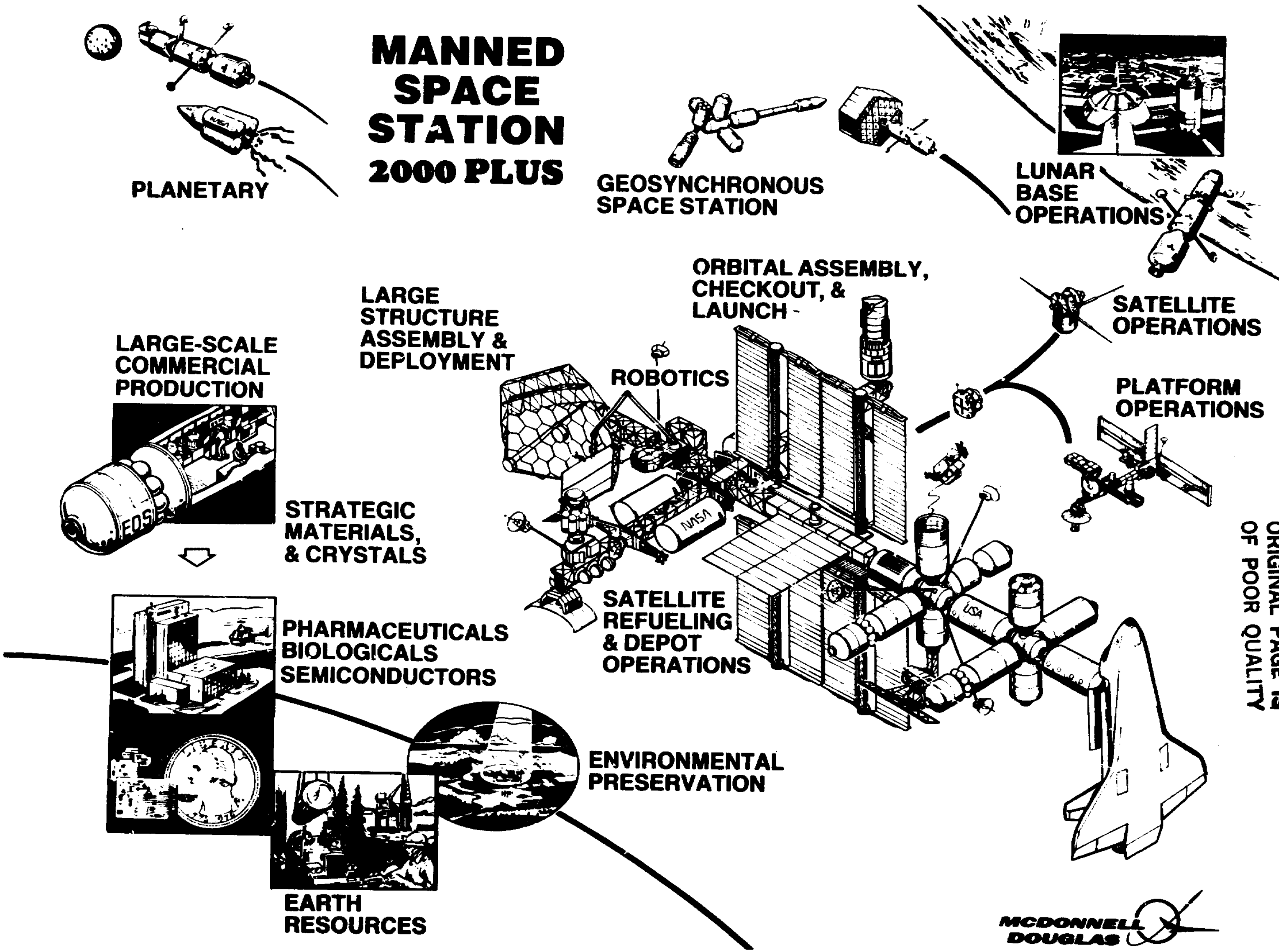
MAJOR RECOMMENDATIONS

- Establish Permanent User Interaction
  - — Need User's Guide
  - — Need User Charge Policy
- Continue Systematic Study
  - — Develop Next Level Requirements
  - — Focus R&D on Limiting Technologies
- Concept Definition Should Stress:
  - — Modular Functions; Modular Size
  - — "Design-to-Cost" Approach
- Key Issues:
  - — Mission Priorities/Mission Costs
  - — STS/Space Station Transition Phase
    - ■ Mission Preparation ■ STS Capability
  - — System/Operational Issues:
    - ■ Autonomy ■ Crew Role
    - ■ Data Management ■ Mission Management

The next three charts depict the Space Station evolutionary buildup from the initial station capabilities in the early 1990s to the expanded capability envisioned after the turn of the century.


MANNED SPACE STATION
ASTROPHYSICS
SATELLITE SERVICING
OPERATIONS
TECHNOLOGY
ATMOSPHERIC SCIENCES
MATERIAL PROCESSING R&D
PLATFORM SERVICING
COMMERCIAL
MATERIAL PROCESSING & MANUFACTURING
EOS
NASA
USA
SCIENCE & APPLICATIONS
PHARMACEUTICALS
EARTH & ENVIRONMENTAL SCIENCES
SATELLITE RETRIEVAL
EARTH RESOURCES & MONITORING
MCDONNELL DOUGLAS


MANNED SPACE STATION
THE 1990s
COMMUNICATIONS PLATFORM
GEO TRANSPORTATION
TECHNOLOGY TESTING & DEMONSTRATION
ASTROPHYSICS
SATELLITE PLACEMENT
REFUELING TECHNOLOGY
SATELLITE SERVICING & REPAIR
MULTIPRODUCT COMMERCIAL MANUFACTURING
EOS
NASA
LIFE SCIENCES
LOW- COST REUSABLE TRANSPORTATION
USA
PLATFORM SERVICING
PHARMACEUTICALS
BIOLOGICALS
SEMICONDUCTORS
ENVIRONMENTAL SCIENCES
EARTH RESOURCES
MCDONNELL DOUGLAS


MANNED SPACE STATION 2000 PLUS
PLANETARY
GEOSYNCHRONOUS SPACE STATION
LUNAR BASE OPERATIONS
ORBITAL ASSEMBLY, CHECKOUT, & LAUNCH
SATELLITE OPERATIONS
LARGE STRUCTURE ASSEMBLY & DEPLOYMENT
LARGE-SCALE COMMERCIAL PRODUCTION
ROBOTICS
PLATFORM OPERATIONS
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NASA
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STRATEGIC MATERIALS, & CRYSTALS
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PHARMACEUTICALS BIOLOGICALS SEMICONDUCTORS
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